Abstract—Content-Based Image Retrieval (CBIR) techniques have been widely researched and in service with the help of cloud computing like Google Images. However, the images always contain rich sensitive information. In this case, the privacy protection become a big problem as the cloud always can’t be fully trusted. Many privacy-preserving image retrieval schemes have been proposed, in which the image owner can upload the encrypted images to the cloud, and the owner himself or the authorized user can execute the secure retrieval with the help of cloud. Nevertheless, few existing researches notice the multi-source scene which is more practical. In this paper, we analyze the difficulties in Multi-Source Privacy-Preserving Image Retrieval (MSPPIR). Then we use the image in JPEG-format as the example, to propose a scheme called JES-MSIR, namely a novel JPEG image Encryption Scheme which is made for Multi-Source content-based Image Retrieval. JES-MSIR can support the requirements of MSPPIR, including the constant-rounds secure retrieval from multiple sources and the union of multiple sources for better retrieval services. Experiment results and security analysis on the proposed scheme show its efficiency, security and accuracy.

Index Terms—Searchable encryption, Privacy-preserving retrieval, Content-based image retrieval.

1 INTRODUCTION

Imaging device has rapidly become stronger and cheaper with the development of semiconductor technology. In this case, more and more high-resolution images are generated by people from all walks of life every day. The need for efficient storage and retrieval of images is more urgent by the increment of large-scale image databases among all kind of areas. The development of cloud computing brings suitable solution to the computation-intensive and storage-intensive image retrieval task, and many excellent image retrieval schemes [1] have been proposed to put the CBIR into practical applications like Google Search By Image [2].

However, the images always contain rich sensitive information. What’s more, in many cases, images are copyright restricted and the owners hope to profit from them by providing CBIR service. Therefore, it is unsafe to directly upload the unencrypted images to the cloud, which makes us drop into the dilemma between the image retrieval and image security. Many prior works in the field of privacy-preserving CBIR (PPCBIR) have paid their attention to this problem. Briefly speaking, the image owner can upload the encrypted image features or the encrypted images to the Cloud Server (CS), and the CS can execute similarity computation between the encrypted data. A typical system model is shown as Fig. 1.

It should be noticed that most of existing schemes have a common limitation that they only consider the single-source (i.e., single image owner) case [3], where the image owner executes the authorizing and the authorized user retrieve the encrypted images of this owner with the help of CS. However, in real-world applications, image retrieval task is more likely to get multiple image sources involved. Firstly, the users of PPCBIR always hope that they can get more comprehensive search results. It is obviously that multi-source can cope with this problem better. Secondly, the image owners can enhance their competitiveness by uniting and providing their services to the authorized users together. Last but not least, the CS is more willing to server for multi-source to enhance the stability and profitability as they can provide more computation and storage services. The joint demand of all entities makes multi-source an indispensable choice. Some recent works [3]–[5] have noticed the significant meaning of these scenes, however, to the best of our knowledge, no existing paper comprehensively considers MSPPIR and gives the scheme in a safe and efficient way.

It is clear that CBIR is a real-time task. However, to ensure the image security, especially in the multi-source scene, is quite a challenge to the efficiency. In addition, as the image encrypted in spatial domain cannot be compressed a lot, two PPCBIR works [6], [7] try to encrypt images in JPEG-domain. However, these schemes still suffer from the problems like feature leakage, index lacking, etc.

To address these challenges, we propose a new secure scheme JES-MSIR for MSPPIR, in which we consider two
basic requirements that are different from the scenario with a single image owner. In total, the contributions of this paper can be summarized as follows:

1) We formally defined the MSPPIR problem in terms of functionality and security. Firstly, the authorized user should be able to execute the retrieval from all the owners, who authorize to him, with constant (i.e. irrelevant to the number of owners) rounds of communication to the CS. Secondly, a part of owners should be able to unite as a group to provide the retrieval service together. Finally, the security should be considered under the reasonable treat model. 

2) We propose a novel scheme which can support MSPPIR efficiently. The permutations are used to ensure the security and accuracy. The property of permutation is further exploited to deal with the collusion problem and support the union of sources. The image encrypted is conducted with the quantized DCT coefficients in JPEG-format images to avoid the file expansion. The bag-of-words (BOW) and multiple permutations are utilized to cope with the problems like low retrieval efficiency and feature leakage in the existing JPEG-domain single-source PPCBIR schemes.

3) We make detailed experiments on two real-world image databases. It is shown that the efficiency and retrieval accuracy of our scheme are better than the existing schemes which just partly support multi-source, and the security is on par with the existing PPCBIR schemes.

The rest of our paper is organized as follows. Section 2 summaries the related works, specially, we give the explanations about why most of the single-source schemes are not suitable for the multi-source scene. Section 3 introduce the system architecture and preliminaries. The detailed scheme design is presented in Section 4 and Section 5. The Section 6 gives the security analysis. Experiments and results are presented in Section 7. Finally, conclusions are made in Section 8.

2 RELATED WORK

Existing schemes on PPCBIR can be briefly classified into two categories. In the first category, the image owner firstly extracts the aggregated feature from plaintext image, then use specific encryption methods to encrypt the feature or index. The image owner uploads the encrypted features and encrypted images to CS at last. CS can execute the retrieval in encrypted domain with specific similarity measurement methods. In the second category, the owner just needs to encrypt the image, the tasks of feature extraction and index building are all undertaken by CS, which makes an ideal environment for MSPPIR. The kernel difference is that feature extracted before or after the encrypted image upload and we detailedly discuss these schemes in the follow.

2.1 Feature-encryption based schemes

Due to the feature extraction task undertaken by the owner, the kernel task of schemes in first category is constructing a function encryption on the feature to make the distance between encrypted features valid. The methods can be broadly divided into two classes [8]: those based on randomization symmetric encryption techniques and those based on homomorphic encryption. To the best of our knowledge, Lu et al. [9] proposed the first PPCBIR scheme over the encrypted image database. The scheme uses min-hash algorithm and order-preserving encryption to protect the visual words which are utilized to represent the images. In the another work, Lu et al. [10] investigates three image feature protection techniques including bit-plane randomization, random projection and randomized unary encoding. Based on the property of bit computation, the encrypted feature is still valid for retrieval. Xia et al. [11] proposed a PPCBIR scheme based on Scale-Invariant Feature Transformation (SIFT) [12] features and Earth Mover’s Distance (EMD) [13]. The calculation of EMD is in fact a linear program problem, and a linear transformation was utilized to protect the privacy information during the solution process of EMD problem. Yuan et al. [14] designed an encrypted image search scheme based on the secure KNN (k-nearest neighbors) [15] algorithm and outsourced most of index building task to CS. The above methods are all belong to the randomization symmetric encryption techniques.

Homomorphic encryption (HE) technology is a cryptography technology based on computational complexity theory of mathematical problems. Some early works [16]. [17] considered the secure distance computation of feature vector based on the Somewhat Homomorphic Encryption (SHE) [18] which can support addition or multiplication on ciphertext, however, they are not a practical scheme in the PPCBIR as they expose part of plaintext feature. To the best of our knowledge, Lu et al. [8] firstly pointed out that the SHE methods can’t complete the secure retrieval without the interactions with the authorized user. They further prove that although CS can execute the retrieval based on Fully Homomorphic Encryption (FHE) [19] technology which can support the addition and multiplication on ciphertext, the time and storage consumption are far more than the methods based on randomization distance-preserving encryption. The other schemes [3], [4] in this type will be detailed described later.

2.2 Image-encryption based schemes

The strategies in the first category suffer from a common disadvantage. As the big volume of storage and large computation complexity, both the image feature extraction and index construction are resource-consuming operations. In this case, the researchers try to outsource the feature extraction task to the cloud, which brings up the methods in the second category. Similar to the first category, the methods in second category can be briefly classified into two classes. The first one tries to extract the encrypted classic feature (e.g., SIFT) from the encrypted images through SHE technology, and the second uses invariant statistics as the feature based on random encryption. To our knowledge, Hsu et al. [20] was the first to investigate privacy-preserving SIFT in the encrypted domain by utilizing Paillier cryptosystem. However, their scheme is computationally intractable and insecure [21]. The following schemes [22], [23] in this class
try to improve their practicability by using two CS work collaboratively. In recent years, more researchers try to use pre-trained VGG16 as feature extractor to extract encrypted feature. However, the time and storage consumption taken by HE on image and plenty of interactions between servers is still hard to accept. The kernel reason for high complexity is large number of nonlinear feature extraction operations on encrypted image.

The methods based on invariant statistics is the scheme which users and CS are both low computational cost, and it makes the scheme the most practical one. Ferreira et al. [5] proposed a tailor-made Image Encryption Scheme called IES-CBIR. In this scheme, random permutation is employed to protect the value (i.e., color) information and the position (i.e., texture) of image pixels is shuffled randomly. After encryption, owner sends the encrypted images to CS. The HSV (i.e., texture) of image pixels is shuffled randomly. After encryption, the encrypted images are extracted from the encrypted images at the cloud server side. The similarities between images can be directly measured by Hamming distances between the corresponding histograms. However, the global histogram is too rigid for image retrieval problems. Xia et al. [25] further extracted local histogram as the local feature, and get better aggregating feature with the help of BOW. However, the schemes in spatial domain will destroy the image compression, and the encrypted images have to be stored in lossless-compression format (PNG, zip), thus it will bring the extra storage and time consumption. A valid solution of this problem is to encrypt the image in JPEG-domain, and keep the JPEG-format be hold after the encryption. Zhang et al. [2] encrypts the JPEG image by permuting the DCT coefficients of different blocks at the same frequency position, and Cheng et al. [6] permutes the entropy-coded segments in the JPEG bitstream. However, these schemes exposed the feature of plaintext. To avoid this problem, Liang et al. [26] encrypted the Huffman-code histograms. However, their schemes are still fragile in the Known-Background-Attack (KBA) model. What’s more, the previous works in JPEG-domain did not give the feature aggregation scheme, which will make the retrieval time unacceptable.

2.3 Partly supported MSPIIR

Although most of the mainstream schemes in the PPCBIR are mentioned above, few papers above considered the scene of multi-source. A straightforward idea is extending existing schemes to multi-source scenario by executing searching over encrypted images belong to different owners one by one. However, it will introduce plenty of rounds of communications between authorized users and CS. A necessary improvement is performing multiple retrieval at constant rounds (e.g., one interaction). However, in this case, the randomization based scheme in the first category is vulnerable to malicious image owner. For example, the stream cipher key is exposed when the attacker get the ciphertext and its plaintext, which make the collusion between the image owner and CS become threaten. Besides, the union expansion of schemes in the first category is still an open problem. The scheme based on classic feature extraction in the second category is also unsuitable for the multi-source expansion as the time-consumption will be more unacceptable. Some other methods unmentioned above like partial encryption [27, 28] is also unsuitable for the scalability in that the security risk in the single-source will be more magnified.

To our knowledge, there are three existing schemes which partly support the multi-source scene. Shen et al. [3] firstly point out the significant meaning of retrieval multi-source in one interaction, they propose a scheme called MIPP based on the methods in secure multi-party computation (SMC) [29], which supports the sum of ciphertext is same as the sum of plaintext. The scheme let each image owner encrypt their feature vector by their own key and use their sum as an evaluation of distance. To avoid the interaction between the image owner and authorized user during the retrieval, key management center (KMC) is introduced to decrypt the image belong to image owner, then encrypt it with the key from the authorized user. However, on the one hand, this evaluation is not suitable for the image, which make their retrieval accuracy not good. On the other hand, the scheme exposes the sum of plaintext features to the CS and expose the plaintext image to the KMC, which make their scheme insecure. Zhang et al. [4] proposed a feasible scheme called PIC based on multi-level FHE which support the key conversion in the encrypted domain [30]. The CS and KMC both possess partial secret key. When an user add into the system, the trusted party (TP) distribute the secret key to the user, CS and KMC, which make the ciphertext can be transformed to the same key by the collaborative computing. Although their scheme can get similar accuracy with the plaintext, the time consumption caused by multi-level FHE is unacceptable. Besides, the security of this scheme is based on a global secret key, which make it vulnerable to collusion attack (i.e., the collusion between the CS and KMC). The above two schemes can be regarded as the scheme in the first category and they only consider about the scene about single user authorized by multi-source. In [5], a brief discussion about the union between the owners are given. In their scheme, an owner creates the repository, when the other users join in, they need to use the repository key to encrypt the pixel color features, and the users can encrypt their pixel positions by their own. However, it will make the image owner execute extra consumption when they join in a repository. What’s more, the following paper in the second category are all paying little attention to the scene that users authorized by multi-source.

As the description above, existing schemes on MSPIIR are suffering from the shortage on the accuracy, security, efficiency and scalability. Inspired by existing schemes based on invariant statistics in the second category, we propose a novel system model in Section 3, and show the complete scheme in Section 4 and Section 5 to cope with challenges on multi-source PPCBIR scene.

3 SYSTEM MODEL AND PRELIMINARIES

3.1 System model

Similar to [4] and [5], the proposed system involves five types of entities, i.e., the image owner, the group, Cloud Server (CS), Key Management Center (KMC) and the Authorized User (AU), as shown in Fig. 2.

Image owner has a corresponding identity which can be called as OID. Each image owner has a large-scale image
Fig. 2: System model. In the figure, the process of outsourcing images, authorizing users and user executes query are shown.

database $I_{OID} = \{I_i\}_{i=1}^{n_{OID}}$. Each image belong to an owner has a corresponding identity set $IID_{OID} = \{IID_i\}_{i=1}^{n_{OID}}$, where the $n_{OID}$ means the number of the images the owner has. To preserve the security of images, before uploading, each owner generates an encrypted image set $C = \{C_i\}_{i=1}^{n_{OID}}$ from $I_{OID}$ by image encryption.

**Group** with a group identity $GID$ is an union of several image owners. The goal of Group is to give better service for the authorized users, which means after the user authorized by the group, he can search all the images belong to the image owners in the group without interaction with them. The **group organizer** take the responsibility to authorize the users and update the members. The group organizer should be trusty to all the members in group. The group organizer could be undertaken by a trusty member or trusty third party.

**Cloud Server** stores the encrypted images from the image owners and provides CBIR service for users. What’s more, the cloud server will further extract aggregate feature from the encrypted images for the owner and group to get better retrieval time.

**Key Management Center** takes the responsibility for storing the key for each image and the authorized information. When a owner adds a new encrypted image to the CS or authorize a user, he will send a corresponding key to key management center. Two keys will be got when the group organizer authorize a new user. During the retrieval, CS needs one interaction with KMC.

**Authorized User** with a corresponding identity called as $UID$ can be authorized by multiple owners/groups, and they can get the retrieval results from all the authoring sources with a single interaction. Authorized users need no interactions with KMC.

As authentication information, CS and KMC have the knowledge of $OID$ (i.e., set of $OID$), $GID$ (i.e., set of $GID$) and $UID$ (i.e., set of $UID$) and the authorization relationship between them. In the rest of paper, for simplicity, $source$ is used to represent the image owner and the group.

### 3.2 Security model

Similar to previous schemes [4, 5], the honest-but-curious CS and KMC are considered in our scheme, i.e., they will follow the protocol specification, but may try their best to harvest the content of the encrypted images. In general, CS and KMC are well protected, so we don’t consider compromise attack in this paper.

As we could set the CS and KMC in different service providers (i.e., Google and Amazon) and the authorized user will not interact with the KMC, we assume that it is not possible to have an authorized user who collude with both CS and KMC. Similar, as the union of group implies the assumption owner in group is highly believable, we assume both CS and KMC collude with an image owner in one group is impossible. As the group organizer need not do more thing besides key generation and distribution, we assume the group organizer is trusty to all the members in the group. Same as previous schemes [4], the collusion between entities only include the existing information exchange, the further defraud collaboratively is beyond consideration as it is easy to be detected by other non-collusion server.

### 3.3 Preliminaries

#### 3.3.1 Overview of JPEG encoding

JPEG is the most commonly used image format and accounting for up to 95% of the images in the web [31]. Generally speaking, it will be faster to operate the JPEG image without decoding. To better explain the image encryption and feature extraction operations, we here briefly introduce color JPEG encoding.

As we all know, the color image is composed by a number of pixels which are represented by RGB values. Based on the characteristics that human eyes are insensitive to chrominance information and high frequency information, the JPEG encoding firstly transforms the RGB information to YUV pattern, then down-sampling the UV information (i.e., $Y:U:V=4:1:1$). Then the image is split to a series of $8\times 8$ non-overlapped blocks, and DCT transformation are executed on each block. As a result, the RGB values in a block are transformed as one DC value and 63 AC values. At last, the quantization table are used to compress these values, the higher frequency information which means the relatively later part of AC values will be strongly squeezed, and most of AC values will be squeezed to zero.

Due to the dependency of the adjacent image blocks, the difference value between two sequential DCT blocks is calculated to represent the DC value. Due to most of the AC values is zero, the zig-zag scan and run-length encoding are used to encode 63 AC values in each block. For example, suppose the zig-zag sequence of a block is $\{(3,-8,0,-1,0,0,0,3,0,0,-4,EOB)\}$ that can be converted into serveral $(r,v)$ pairs: $\{(0,5), (0,-8), (1,-1), (3,3), (2,-4), (0,0)\}$, where $r$ denotes the number of zeros before a non-zero AC coefficient whose value equals to $v$. The symbol EOB (End-Of-Block) implies that all remaining AC coefficients in the block are zero, and denotes as one specific pair $(0,0)$. The huffman code and VLI code table is finally used to encode the DC difference value and $(r,v)$ pairs with VLI code table shown in Table 1, one VLI code is composed by the bit-stream and the group it belong to. For simplicity, in the rest of paper, the bit-stream of DC difference value will be called as $DC$, and the group index of $DC$ will be denoted as $g_{DC}$. It is easy to find that the $DC$ and $(r,v)$ pairs contains nearly all the information of image.
3.3.2 Bag-of-word model

The CBIR technologies extract visual features to represent the images. During the early stages of its development, global features [32] are extracted from the image to perform the retrieval. However, the global feature is always easy to be affected by the illumination and rotation etc. The local features (e.g., SIFT) are used to solve this problem. However, the local features are always too large and instable, in this case, the feature aggregation methods are gradually developed. The BOW (Bag-Of-Word) [33] is one of the most popular models. There are three steps in the BOW model:

(i) Local histogram extraction. The first step is to extract local features from the images in database. The local feature (e.g., SIFT) is commonly used in the CBIR. However, to encrypted images, on the one hand, the local feature is not outstanding in low-resolution image without suitable aggregation methods; on the other hand, non-linear decryption schemes local feature uses make the feature extraction from encrypted image difficult [20], [22].

(ii) Vocabulary generation. The second step is to construct the visual vocabulary. Typically, k-means method can be employed to cluster the local features into k classes. The cluster centers are defined as visual words. The full set of the visual words constitute the vocabulary.

(iii) Histogram calculation. The last step is to calculate the histogram of visual words. All the local features are represented by their nearest visual words. Finally, each image is represented by a k-bins histogram of visual words. It should be noticed the position of the visual words have been ignored in this way, and it give the space for the encryption.

3.3.3 Permutation and Bitxor

The permutation encryption and bitxor encryption is widely used in the encryption on features [9] and images [5], [6], [25]. In these schemes, symmetric secret keys are used during the encryption and decryption. The permutation-based encryption and decryption is presented in algorithm 1 and algorithm 2.

For simplicity, the orderly sequence of positive integers from 1 to N is denoted as EN. For example, E3 denotes the sequence (1, 2, 3). In the existing schemes [5], [6], [10], [25], the permutation key is used to encrypt the plaintext features or images, which means input data of EncPerm can be seen as E. To meet the needs of MSPPIR, the transformation between secret keys are further considered. From the basic properties of permutation group, it is easy to get formula [1]

\[
\text{EncPerm}(\text{DecPerm}(K_2, K_1), \text{EncPerm}(K_1, K)) = \text{EncPerm}(K_2, K)
\]

(1)

Specially, we can get formula [2] when we set K = E.

\[
\text{EncPerm}(\text{DecPerm}(K_2, K_1), \text{EncPerm}(K_1, E)) = \text{EncPerm}(K_2, E)
\]

(2)

It should be noticed that for each D, there is a corresponding K can get the same DecPerm(D, K). The primary fact means that it will be difficult to infer D or K from the DecPerm(D, K) only. Based on same reason, it further implies that exposed DecPerm(K2, K1) and EncPerm(K1, K) will not leak the K, K1 and K2. It is easy to notice that the BitXor (Bit-wise XOR) computation has the same property.

4 Basic scheme

In this section, we only consider the scene the authorized user search from multi-owners, the enhancement on security and the scheme of group union will be given in the next
section. The proposed scheme is given from the perspective of different entities.

4.1 Owner Side

4.1.1 Image Key Generation

As mentioned in subsection 3.3.3, the JPEG-format image is mainly made up of DC values and \((r, v)\) pairs. Similar with the image in spatial-domain, the image can be separated into two kinds of information, i.e., value information and position information. To protect the image content, we firstly shuffled the non-overlapping blocks. Next the \((r, v)\) pairs in each block are shuffled to further protect the position information. Finally, the \(v\) and DC values are substituted to protect the value information.

The \(K_p\) is used to encrypt the position information of image. In JPEG-domain, it contains the block permutation, intra-block permutation and the bitstream in one file length. Accordingly, a pseudo-random permutation generator, a stream-cipher generator and several keys are used to protect the position information, i.e., \(K_p = \{\text{RandPerm}, \text{StmCiph}, \text{key}_{\text{yldor}}, \text{key}_{\text{ymlblos}}, \text{key}_{\text{ydlb}}, \text{key}_{\text{yuc}}\}\). For simplicity, the following \(\ast\) represent an element in \(\{Y, U, V\}\).

The secret key \(\text{key}_{\text{yldor}}\) is used to permute the blocks in image from the range \([1, \ldots, \text{blknum}_{\ast}]\), the \(\text{blknum}_{\ast}\) is the number of non-overlapping blocks in the corresponding color component. The random permutation is generated as follows:

\[
pmtb_{\ast} \leftarrow \text{RandPerm}(\text{key}_{\text{yldor}}, [1, \ldots, \text{blknum}_{\ast}], IID). \quad (3)
\]

The secret keys \(\{\text{key}_{\text{ymlblos}}\}\) are used to generate random permutations to shuffle \((r, v)\) pairs in blocks. The random permutations of three components are generated as follows:

\[
\{pmt_{\ast j}\} \leftarrow \text{RandPerm}(\text{key}_{\text{ymlblos}}, [1, \ldots, \text{blksize}_{\ast j}], IID, j_{\ast}), \quad (4)
\]

where \(\text{blksize}_{\ast j}\) means the number of \((r, v)\) pairs in \(j_{\ast}\)-th block, \(j_{\ast} \in [1, \ldots, \text{blknum}_{\ast}]\).

Due to we need to control the bit-length of encrypted DC for further retrieval, it is difficult to generate the bitstream to encrypt DC before encryption. In this case, we directly use \(\text{key}_{\text{ydc}}\) to generate the encrypted DC, the random bitstream is generated as follow:

\[
\{\text{bitdc}_{\ast j}\} \leftarrow \text{StmCiph}(\text{key}_{\text{ydc}}, [1, \ldots, \text{blksize}_{\ast j}], IID, j_{\ast}). \quad (5)
\]

Accordingly, a pseudo-random permutation generator and several secret keys are used to protect the value information, i.e., \(K_v = \{\text{RandPerm}, \text{key}_{\ast v}, \text{key}_{\ast y}\}\).

The secret keys \(\text{key}_{\ast v}\) are utilized to generate random permutations to substitute the value of \(v\) in all the blocks. As most absolute value of \(v\) is less than 10, the random permutations are generated as follows:

\[
\{pmt_{\ast v, \#}\} \leftarrow \text{RandPerm}(\text{key}_{\ast v}, [-10, -1] \cup [1, 10]), \quad (6)
\]

The secret keys \(\{\text{key}_{\ast y}\}\) are used to generate the random permutations to substitute the value of \(y\) in all the blocks. As most absolute value of \(y\) is less than 10, the random permutations are generated as follows:

\[
\{pmt_{\ast y, \#}\} \leftarrow \text{RandPerm}(\text{key}_{\ast y}, [-10, -1] \cup [1, 10]), \quad (6)
\]

As mentioned in subsection 3.3.1, the JPEG-format image is mainly made up of DC values and \((r, v)\) pairs. Similar with the image in JPEG-domain, the image can be separated into two kinds of information, i.e., value information and position information. In JPEG-domain, it contains the block permutations for each color component. The permutations are generated as follows:

\[
\{pmtDCL_{\ast \#}\} \leftarrow \text{RandPerm}(\text{key}_{\ast}, [0, 9]), \quad (7)
\]

The secret keys \(\{\text{key}_{\ast}\}\) are used to generate the random permutations to substitute the \(g_{DC}\). As most \(g_{DC}\) is less than 10, the random permutations are generated from the range \([0,9]\) as follows:

\[
\{pmt_{DCL_{\ast \#}}\} \leftarrow \text{RandPerm}(\text{key}_{\ast}, [0, 9]), \quad (7)
\]

4.1.2 Image Outsourcing

\((C, \text{ImgPosKey}, \text{ImgValKey}) \leftarrow \text{ImgEnc}(I, IID, K_v)\). As presented above, three steps are contained in the image encryption including block permutation, intra-block permutation, value substitution. For each step, we present a sub-algorithm to specify its process (see Algorithm 3, 4, and 5).

\[
\begin{align*}
\text{Algorithm 3 BlockPerm} & \\
\text{Input:} & \text{Image } I, \text{the corresponding } IID \text{ and secret keys } \{\text{key}_{\text{yldor}}\} \\
\text{Output:} & \text{Encrypted image } I', \{\text{pmtb}_{\ast}\} \\
1: & \text{Parse the image, and denote the total number of blocks in image } I \text{ as blknum}_{\ast} \\
2: & \text{Generate the secret permutation } pmtb_{\ast} \text{ whose size is blknum}_{\ast} \\
3: & \text{Denote the blocks in } I \text{ as blk}, \text{denote the blocks in } I' \text{ as blk}' \\
4: & \text{for } \ast \in \{Y, U, V\} \text{ do} \\
5: & \text{for } i = 1 : \text{blknum}_{\ast} \text{ do} \\
6: & \text{blk}_{\ast i}' \leftarrow \text{blk}_{\ast}[pmtb_{\ast}[i]] \\
7: & \text{end for} \\
8: & \text{end for} \\
9: & \text{Denote all the pmt}_{\ast j} \text{ as } \{pmt_{\ast j}\} \\
10: & \text{end for}
\end{align*}
\]

\[
\begin{align*}
\text{Algorithm 4 IntraBlockPerm} & \\
\text{Input:} & \text{Image } I, \text{the corresponding } IID \text{ and secret keys } \{\text{key}_{\text{yldor}}\} \\
\text{Output:} & \text{Encrypted image } I', \{\text{pmt}_{\ast j}\} \\
1: & \text{Parse the image, and get the blocks denoted by blk}_{\ast} \\
2: & \text{for } \ast \in \{Y, U, V\} \text{ do} \\
3: & \text{for } \text{blk}_{\ast j} \in \text{blk}_{\ast} \text{ do} \\
4: & \text{Generate the secret permutation for } j-\text{th block blk}_{\ast j} \text{ size of blksize}_{\ast j} \text{ as pmt}_{\ast j} \\
5: & \text{for } \text{blk}_{\ast j}[i] \in \text{blk}_{\ast j} \text{ do} \\
6: & \text{blk}_{\ast j}'[i] \leftarrow \text{blk}_{\ast j}[pmt_{\ast j}[i]] \\
7: & \text{end for} \\
8: & \text{end for} \\
9: & \text{Denote all the pmt}_{\ast j} \text{ as } \{pmt_{\ast j}\} \\
10: & \text{end for}
\end{align*}
\]

As presented by Algorithm 3 and 4, we generate the random permutations to shuffle the block position and intra-block \((r, v)\) pairs. It should be noticed that the \(K_v\) is unique for each owner, but the \(K_p\) is one-time pad for each image.
It should be noticed that all the encryption methods are privacy-preservation, the OID as shown in section 6. It helps to resist the collusion between image owner and CS.

\section*{Algorithm 5 ValueSubstitution}

\textbf{Input:} Image I and secret keys \{key$_{ev}$\}, \{key$_{i}$\} and key$_{dc}$

\textbf{Output:} Encrypted image $I'$, \{pmtnv$_{v}$\#} and \{pmtdCL$_{s}$\#}, \{bitkey$_{v}$\}

1. Generate the secret permutations pmtnv$_{v}$\#, pmtnv$_{v}$\#,
   pmtnv$_{v}$\# where \# $\in \{1, \ldots, Npmtnv\}$; Each permutation table is 20-dim, which is a random permutation of $[-10, -1]$ $\cup [1, 10]$.
2. Generate the secret permutations pmtdCL$_{Y}$\#, pmtdCL$_{U}$\#, pmtdCL$_{V}$\# where \# $\in \{1, \ldots, Npmtnv$2\}$.
   Each permutation table is 10-dim, which is a random permutation of [0, 9].
3. Generate six sequences sqnt$_{1s}$ and sqnt$_{2s}$. The length of sequences are equal to the block amount of the image I and the element of sqnt$_{1s}$ are the repeat of E$_{Npmtnv}$. For instance, if the N$_{pmtnv}$ = 5, and the image have 12 blocks, the sqnt$_{1s}$ $\{1, 2, 3, 4, 5, 1, 2, 3, 4, 5, 1, 2\}$. Similarly, sqnt$_{2s}$ are generated by N$_{pmtnv}$.
4. Parse the image and get the \{\{(r$_{ij}$, v$_{ij}$)$_{blksize}$\#\}, \{DC$_{i}$\#\}$_{i=1}^{blknum}$.  
5. for $v \in \{Y, U, V\}$ do
6.    for $i = 1 : blknum$, $do$
7.        for $j = 1 : blksize$_{i}$, $do$
8.            enc$_{ij}$ = pmtnv$_{v}$,sqnt$_{1s}$,i [v$_{ij}$]
9.        $end$ for
10. Generate a random bitstream bitdc$_{sv}$, then only save last pmtdCL$_{s}$,sqnt$_{2s}$[DC$_{i}$] bit as the encDC$_{i}$.
11. Compute bitkey$_{i}$ = encDC$_{i} \oplus DC_{i}$
12. $end$ for
13. Denote all the bitkey$_{i}$ as \{bitkey$_{v}$\}.
14. The \{\{(r$_{ij}$, enc$_{ij}$)$_{blksize}$\#\}$_{i=1}^{blknum}$\} and \{encDC$_{i}$\}$_{i=1}^{blknum}$ compose encrypted image $I'$.
15. $end$ for

\section*{Algorithm 6 ImgEnc}

\textbf{Input:} Image I, the corresponding IID and $K_v$

\textbf{Output:} Encrypted image C, ImgPosKey(OID,IID) and ImgValKey$_{OID}$

1. Randomly generate $K_p$
2. (I$_i$, pmtnb$_i$) = BlockPermut(I$_i$, {key$_{ylos}$})
3. (I$_i''$, {pmtp$_s$}) = IntraBlockPermut(I$_i''$, {key$_{yinblos}$, \#})
4. (C, \{bitkey$_i$\}, \{pmtdCL$_{s}$\#\}, \{pmtnv$_{v}$\#\}) = ValueSubstitution(I$_i''$, key$_{v}$, key$_{ylos}$, key$_{dc}$)
5. Denote the \{pmtnb$_i$, \{pmtp$_s$\}, \{bitkey$_i$\} as the ImgPosKey(OID,IID), denote the \{pmtdCL$_{s}$\#\}, \{pmtnv$_{v}$\#\} as the ImgValKey$_{OID}$

\section*{Algorithm 7 TrapGen}

\textbf{Input:} Image I, $K_v$.

\textbf{Output:} Encrypted query images \{C$_{OID}$\}

1. for each OID who authoring \textbf{do}
2.   Randomly generate a $K_p$ and a \{key$_{ylos}$\}
3.   (I$_i''$, \#) = BlockPermut(I$_i''$, \{key$_{ylos}$\})
4.   (I$_i'''$, \#) = IntraBlockPermut(I$_i'''$, \{key$_{yinblos}$\})
5.   (C$_{ OID}$, \#, \#, \#) = BlockPermut(I$_i'''$, \{key$_{ylos}$\})
6. $end$ for

5. $C$ to the CS, and send the corresponding encryption key ImgPosKey(OID,IID) to the KMC.

\subsection*{4.1.3 User authorization}

When one image owner with identity OID wants to authorize the user, he will give the user ImgValKey$_{OID}$ for the retrieval and decryption. The authorization information will also be known by CS and KMC. The further operations during authorization will be introduced in subsection 5.1.2.

\subsection*{4.2 Authorized user Side}

The authorized user wants to search the similar images from the owners who authorize him. As shown in algorithm 7, the user just needs to encrypt the query image with ImgValKey he gets from the owners. It is noteworthy that encrypted query is at last protected by the BlockPermut, which means the relationship of block is destroyed. After encryption, authorized user only need to send all the encrypted query with corresponding OID as the trapdoor to CS.

\subsection*{4.3 Cloud Side}

After the owners upload the encrypted images, for the efficiency of retrieval, the CS will extract high-quality encrypted feature and further build the index for images in the database. As the process of index building is similar to the plaintext situation, we here focus on encrypted feature extraction and aggregation process.

\subsubsection*{4.3.1 Global feature extraction from encrypted DC}

The gDC is extracted to represent DC information of encrypted image [35]. As most values of gDC are concentrated in [0,9], the CS can extract a 10-dim feature, in which the jth-dim represents the number of gDC whose value equals to j. The YUV further form a 30-dim feature vector f$^{DC}$.

\subsubsection*{4.3.2 Aggregation feature extraction from the encrypted AC}

Different from DC, it is difficult to represent the AC values in a block effectively by a single number and it makes the feature aggregation an indispensable step. Inspired by [25], we use the typical BOW model to aggregate the features. The kernel observation here is that the encrypted histogram can still be used to compute the distance and k-means method BOW [35] uses is robust to the element permutation. Accordingly, the aggregation for encrypted AC values consists the following three steps:

```plaintext
positions can be substituted with different values, which helps to resist the statistic attacked [34, 35]. What’s more, it helps to resist the collusion between image owner and CS as shown in section 6.

As shown in Algorithm 6, we denote the \{pmtnb$_i$, \{pmtp$_s$\}, \{bitkey$_i$\} as the ImgPosKey(OID,IID). For simplicity, the OID and IID will be omitted when there is no ambiguity or in general reference in the rest of paper. It should be noticed that all the encryption methods are high-efficiency bit computation or vector operation. After encryption, the owner should send the encrypted image.
(i) Local histogram extraction. A 40-dim vector is extracted to represent the feature of encrypted AC in each block, which is composed by three parts as follow.

\[ f_{ACLocal} = Hist_s \parallel Hist_v \parallel Hist_r. \]  

The \( Hist_s \) contains the static information of \((r, v)\) pairs, including the number of \((r, v)\) pairs, the mean and standard deviation of \(v\). The \( Hist_v \) is the distribution information of \(v\). Detailedly, the value of 21-dim is the number of occurrences of \(v\) values in the block range from \([-10, 10]\), and the other 2-dim represents the \(v\) values more than 10 or less than -10. The \( Hist_r \) is the value information of \(r\). The 14 biggest value of \(r\) form the vector in descending order. If the number of \((r, v)\) pairs is less than 14, the unfilled elements of \( Hist_r \) will be filled by -1.

(ii) Vocabulary generation. Cluster all the local features into \(k\) classes with the \(k\)-means clustering algorithm. The \(k\) class centers are defined to be the encrypted visual words which make up the vocabulary. It should be noticed the \(Y, U, V\) are clustered independently as they have different properties naturally. The selection of \(k\) is always a difficult problem, however, the methods like x-means [37] or gap statics [38] can effectively cope with the problem. What’s more, we will show the retrieval accuracy of our scheme is quite robust to \(k\) in Fig. 9.

(iii) Histogram calculation. After generating the vocabulary, all the local histograms in an image are represented by their nearest visual words. As a result, each image is represented by a feature vector \(f = (f_1)_{i=1}^{k}\). A "scaled tf-idf" [39] trick is further implemented to optimize the feature \(f_Y, f_U, f_V\), which means the finally extracted feature vectors from the \((r, v)\) pairs.

Finally, the image identities and the feature vector make up a linear index. It is easy to see that the feature vector are encrypted but the common index building schemes (e.g., tree indexing [40]) can be further used.

4.3.3 Search operation

When the CS get the trapdoor generated by the authorized user, it will extract the same format feature as that from images in the dataset. If the query is limited in a single owner, the CS will calculate the feature with the corresponding visual words. Detailedly, the distance are calculated as formula (9), where \(D(\cdot, \cdot)\) means manhattan distance.

\[
Dis(I_1, I_2) = \alpha_1D(f_1^{DC}, f_2^{DC}) + \alpha_2D(f_1^Y, f_2^Y) + \alpha_3D(f_1^U, f_2^U) + \alpha_4D(f_1^V, f_2^V)
\]

Follow the experience and experiment, we set \(\alpha_1 = 0.1, \alpha_2 = 0.5, \alpha_3 = \alpha_4 = 0.2\).

4.3.4 Search operation from multiple image owners

The above encrypted feature extraction are still valid during the retrieval as the manhattan distance won’t change if we execute the same permutation on the elements of feature vectors. When the multiple permutation tables are used, the high-frequency values will be randomly substituted to \(N_{pmt}\) different value, where \(N_{pmt}\) is the number of tables. It means if the value frequency distribution of two images is similar, the frequency of encrypted images will still have an extent of similarity, although the frequency become smoother with the increment of \(N_{pmt}\). The distance becomes weak, however, the magnitude relationship is still basically kept which is demonstrated experimentally.

It further implies if the images are encrypted by the permutation tables in same \(N_{pmt}\), the distance after encryption are still at the same level even though different permutations are utilized for encryption. It means the formula [10] set on if we use the above encryption methods, where \(Enc_{\text{ocl}} \) and \(Enc_{\text{enc}}\) means the image encrypted with different \(ImgValKey\) and \(ImgPosKey\).

\[
Dis(Enc_{\text{ocl}}, Enc_{\text{enc}}) = Dis(Enc_{\text{enc}}, Enc_{\text{enc}})
\]

It should be noticed the indispensable aggregation schemes will also infect the distance relationship. To keep the distance can be directly compared, the same cluster number \(k_g\) are used to cluster the images from each image owner. The choice of \(k_g\) will be discussed in subsection 7.2.2.

When the query contains multi-sources, the CS will calculate the feature based on each global visual words, the distance got from different sources will be directly compared together and images with smaller distance will be returned.

4.4 KMC side

After CS gets the similar images, it sends the \((\text{IID}, \text{UID}, \text{OID})\) to KMC. Here, we follow the operation in [5], the CS sends encrypted images \(\{C\}\) to the querier and KMC sends the corresponding \(\{ImgPosKey\}\). The user will decrypt the retrieval results according the key he has got. Notably, it makes users have to interact with the KMC, and actually leads to two rounds of interaction. We will make up the drawback in next section.

5 Advanced Scheme

In the previous section, we give the scheme that can support secure retrieval from multi-source. However, as the \(ImgPosKey\) is directly sent to KMC, it will be fragile to face the collision between CS and KMC. Based on the same reason, the CS and KMC have to interact with user respectively, which leads to extra interaction for user. In this section, we firstly propose the scheme for protecting \(ImgPosKey\) to enhance the security and reduce interaction rounds, then the strategy for group union scene is further given.

5.1 Key protection

Inspired by formula [1], we design a safer scheme with little computation increment during authorization. Briefly speaking, to hidden \(ImgPosKey\), each owner with identity \(OID\) constructs a series of key called as \(UserKey_{\text{KMC}}\). Like formula [1], \(ImgPosKey\) plays the role of \(K_2\), \(UserKey_{\text{KMC}}\) plays the role of \(K_1\). During authorization, the owner will generate and send a random \(UserKey_{\text{UIDOID}}\) which is same format with \(UserKey_{\text{KMC}}\) to the user. For simplicity, the \(OID\) will be omitted in \(UserKey_{\text{UIDOID}}\). The \(UserKey_{\text{UID}}\) plays the role of \(K\) in formula [1]. The work of computing \(EncPer(K_1, K)\) will be undertaken by owner
during authorization, and the result will be stored by KMC. KMC undertakes the computation of $\text{DecPerm}(K_2, K_1)$ during the query. Here we give the construction method of $\text{UserKey}_{\text{OID}}$.

### 5.1.1 UserKey generation

To encrypt the $\text{ImgPosKey}$, owner has to consider all the situation. Detailely, the owner needs to generate the key for encrypting the block-permutation key, intra-block permutation key and the stream cipher. Accordingly, a pseudo-random permutation generator, a stream-cipher generator and several secret keys are included in the $\text{UserKey}$, i.e., $K_u = \{ \text{RandPerm}, \text{StmCiph}, \{ \text{key}_{\text{Ublo}} \}, \{ \text{key}_{\text{Uinblo}} \}, \{ \text{key}_{\text{Udc}} \} \}$

Here, the secret keys $\{ \text{key}_{\text{Ublo}} \}$ are utilized to generate random permutations which are used to encrypt the inter-block permutation keys. As the length of inter-block permutation is determined by the size of images, it is difficult to consider all the situation. However, it can be remedied with a series of permutations whose length are the exponential of two. For simplicity, we here assume the length of images denoted as $\{ \text{CommSize} \}$ are all under consideration, and the random permutations are generated as follows:

$$\{ \text{Upmtb}_{\ast \#} \} \leftarrow \text{RandPerm}(\text{key}_{\text{Uinblo}}, \{ \text{CommSize} \}, \# \in \{1, \ldots, |\{ \text{CommSize} \}| \}, \text{here} \ |\{ \text{CommSize} \}| \text{is the cardinality of set} \{ \text{CommSize} \}. \text{Similarly, the secret keys} \{ \text{key}_{\text{Uinblo}} \} \text{are used to protect the intra-block permutations. As the amount of} (r, v) \text{ pairs is in} [1, 63], \text{it can be generated as follows:}$$

$$\{ \text{Upmtp}_{\ast \#} \} \leftarrow \text{RandPerm}(\text{key}_{\text{Uinblo}}, [1, \ldots, 63], \# \in \{1, \ldots, 63 \}. \text{At last, the} \text{key}_{\text{Udc}} \text{is used to encrypt the bitstream which is computed to decrypt DC. The streamciphers are generated as follows:}$$

$$\{ \text{UbitKey}_{\ast \#} \} \leftarrow \text{StmCiph}((\text{key}_{\text{Udc}}, [1, \ldots, 10], \# \in \{1, \ldots, 10 \} \text{. The whole} \{ \text{Upmtb}_{\ast \#} \}, \{ \text{Upmtp}_{\ast \#} \} \text{and} \{ \text{UbitKey}_{\ast \#} \} \text{is finally denoted as the} \text{UserKey.}$$

### 5.1.2 Image position Key encryption

Different from subsection 4.1.2 after the encryption of an image, the image owner won’t directly send $\text{ImgPosKey}$ to KMC. As the Algorithm 8 the image owner will use the $\text{UserKey}_{\text{OID}}$ to encrypt the $\text{ImgPosKey}$, and then send $\text{ImgPosKey}' = \text{ImgPosKeyEnc}(\text{ImgPosKey}, \text{UserKey}_{\text{OID}})$ to KMC. It should be noticed $\text{UserKey}$ is unique to each image owner, and it will not be exposed to anyone else. The encrypted key $\text{ImgPosKey}'$ are the same format with $\text{ImgPosKey}$.

When the owner authorizes an user, he randomly generates a $\text{UserKey}_{\text{UID}}$ and send to the authorized user. Then owner will use $\text{UserKey}_{\text{UID}}$ to encrypt the $\text{UserKey}_{\text{OID}}$ for following retrieval. As Algorithm 9 shows, the owner executes $\text{UserKeyEnc}(\text{UserKey}_{\text{OID}}, \text{UserKey}_{\text{UID}})$, and sends the result $\text{UserKey}_{\text{OID},UID}$ to KMC.

---

**Algorithm 8 ImgPosKeyEnc**

**Input:** $\text{ImgPosKey}_{\text{UID}}, \text{UserKey}_{\text{OID}}$

**Output:** $\text{ImgPosKey}'_{\text{UID}}$

1. for $\forall \text{Upmtp}_{\ast \#} \in \text{Upmtp}_{\ast \#}$ do
2. seek same length permutation $\text{Upmtb}_{\ast \#}$ in $\text{Upmtb}_{\ast \#}$
3. $\text{Upmtb}_{j \#} = \text{DecPerm}(\text{Upmtb}_{\ast \#}, \text{Upmtb}_{j \#})$
4. end for
5. for $\forall \ast \in \{H, S, V\}$ do
6. seek same length permutation $\text{Upmtb}_{\ast \#}$ in $\text{Upmtb}_{\ast \#}$
7. $\text{Upmtb}_{j \#} = \text{DecPerm}(\text{Upmtb}_{\ast \#}, \text{Upmtb}_{j \#})$
8. end for
9. for $\forall \text{bitkey}_{\ast} \in \{ \text{bitkey}_{\ast} \}$ do
10. seek same length bit-stream $\text{Ubitkey}$ in $\text{Ubitkey}'_{\ast \#}$
11. $\text{bitkey}_{j \#} = \text{bitkey}_{\ast} \oplus \text{Ubitkey}$
12. end for
13. denote $\{ \text{Upmtb}_{\ast \#}, \{ \text{bitkey}_{\ast} \}, \{ \text{bitkey}_{\ast \#} \} \} \text{as the} \text{ImgPosKey}'.$

**Algorithm 9 UserKeyEnc/UserKeyDec**

**Input:** $\text{UserKey}_{\text{OID}}, \text{UserKey}_{\text{UID}}$

**Output:** $\text{UserKey}_{\text{OID},UID}$

1. for $\forall \text{Upmtb}_{\ast \#} \in \text{Upmtb}_{\ast \#}$ do
2. seek same length permutation $\text{Upmtb}_{\ast \#}$ in $\text{Upmtb}_{\ast \#}$
3. $\text{Upmtb}_{j \#} = \text{EncPerm/DecPerm}(\text{Upmtb}_{\text{OID}}, \text{Upmtb}_{j \#})$
4. end for
5. for $\forall \text{Upmtp}_{\ast \#} \in \text{Upmtp}_{\ast \#}$ do
6. seek same length permutation $\text{Upmtp}_{\ast \#}$ in $\text{Upmtp}_{\ast \#}$
7. $\text{Upmtp}_{j \#} = \text{EncPerm/DecPerm}(\text{Upmtp}_{\text{OID}}, \text{Upmtp}_{j \#})$
8. end for
9. for $\forall \text{Ubitkey}_{\ast \#} \in \text{Ubitkey}_{\ast \#}$ do
10. seek same length bit-stream $\text{Ubitkey}_{\ast \#}$ in $\text{Ubitkey}_{\ast \#}$
11. $\text{Ubitkey}_{j \#} = \text{Ubitkey}_{\ast} \oplus \text{Ubitkey}_{\ast \#}$
12. end for

When CS asks the secret key from KMC, KMC will compute $\text{EncImgPosKey}_{\text{UID}} = \text{ImgPosKeyEnc}(\text{ImgPosKey}_{\text{UID}}, \text{UserKey}_{\text{OID},UID})$, and send back to CS. CS will finally send back encrypted images $\{ C \}$ and corresponding $\text{EncImgPosKey}_{\text{UID}}$ to the authorized user. From formula 7, it is easy to notice that the authorized user can get the encryption key with the help of $\text{ImgValKey}$, $\text{EncImgPosKey}'$ and $\text{UserKey}_{\text{UID}}$. 

### 5.2 Group Union

Inspired by [3], the situation that owners unite as a group is further considered. In [3], the creator creates a repository in the CS, and the member join in should use the $\text{ImgValKey}$ creator set to encrypt their images, and further upload them into the repository. It will lead to plenty of extra consumption when owner wants to join different groups. Inspired by formula 2, we accomplish the union by some increment keys. The process of union is shown like figure 3.
When the owners unite as the group, they should firstly choose a trusty member or third party as the group organizer. Similar to the image owner, the group organizer will randomly generate \( UserKey_GID \) and \(ImgValKey_GID \), then send them to all the members in group. After getting these information, to meet the demand of decryption for users who authorized by the group organizer, the members will compute \( IncUsrKey_{OID,GID} = UserKeyDec(UserKey_{OID}, UserKey_{GID}) \), and send the result to KMC. Similarly, in order to meet the demand of retrieval, the members will compute all the \( DecPerm(pmtv_{OID}^{*,#}, pmtv_{GID}^{*,#}) \) and \( DecPerm(pmtDCL_{OID}^{*,#}, pmtDCL_{GID}^{*,#}) \), the results can be denoted as \( IncValKey_{OID,GID} \) then send it to CS. Based on formula (2) the CS could further execute the encryption on encrypted images, then the CS further executes the same operation in subsection 4.3. The \( (r,v) \) part linear index of images for one image owner in CS will be finally built like Table 2.

The group organizer undertakes the task of authorization. Besides the \( UserKey_{OID,GID} \), the group organizer should use the symmetric encryption to avoid the potential collusion risk (shown in subsection 6.2.4). Here we briefly use the AES (Advanced Encryption Standard) [41]. In this case, after the authorization, the group organizer will send \( UserKey_{OID,GID} \) and \( K_{k_{GID,OID}} \) to KMC.

During the retrieval from group, CS will compute the similarity with the feature belong to the group, and then send \( (GID, UID, \{OID\}, \{IID\}) \) to KMC. Based on \( GID \) and \( OID \), KMC can seek the corresponding \( IncUsrKey \). Then KMC will firstly compute \( ImgKeyEnc(ImgPosKey, IncUsrKey) \) based on \( IID \). Then, same to single owner, KMC computes \( EncImgPosKey \) based on the \( UserKey_{GID,UID} \) at last, AES encryption based on corresponding \( k_{k_{GID,UID}} \) will be executed on \( EncImgPosKey \), and the result will be sent back to CS. It is easy to notice the user can finish the decryption based on these information.

### 5.3 Update operation

After introducing all the entities, the update operations in JES-MSIR are given here. Detailly, We will show the update on images and owners.

**Image addition:** As the section 3 based on his \( ImgValKey \) and random \( ImgPosKey \), the owner can get the encrypted image and sends it to CS. Similarly, based on the \( UserKey \), the owner will compute \( ImgKeyEnc(ImgPosKey, UserKey) \) and send it to KMC. The CS will execute the feature extraction by existing visual words, and add this image into the index. The KMC will store the key for following retrieval.

**Image deletion:** The owner with identity \( GID \) sends \( IID \) to CS and KMC. Then CS should delete the corresponding encrypted image and all the feature in the index, KMC should delete the corresponding \( ImgPosKey_{(OID,IID)} \).

**Join group:** The group organizer in the group with identity \( GID \) sends its \( UserKey_{GID} \) and \( ImgValKey_{GID} \) to the new member, then the member, CS and KMC will execute same operation in subsection 5.2.

**Leave group:** The group organizer in the group with identity \( GID \) sends the \( OID \) to CS and KMC. Then CS should delete the corresponding image features which are extracted for the owner and group, KMC should delete the \( IncUsrKey_{(OID,GID)} \).

### 6 Security Analysis

Besides the security problems in PPCBIR [5, 25], MSPPIR [4] also faces the risk from the collusion from different entities. The security analysis in the non-collusion assumption, including Ciphertext-Only Attack (COA) and Known-Background Attack (KBA), will be firstly given in subsection 6.1, then we analysis the potential collusion problems in subsection 6.2. Finally the security comparison with previous schemes in MSPPIR are given in subsection 6.3.

#### 6.1 Security with no Collusion

**6.1.1 Security under COA model**

In the COA model, the adversary is only able to get the ciphertext. As the images are all stored in the CS, we here mainly consider the potential leakage in the CS. For formal statement, the functionality \( F \) and the corresponding information leakages of our scheme under the COA model are summarized in Fig. 4. Our security proofs follow the paradigm in secure multi-party computations [42]. The execution of our scheme involves the interaction between CS and other entities, which is defined as real experiment. In the proposed scheme, the honest-but-curious CS is the potential adversary \( A \). In an ideal experiment, a simulator \( S \) is defined as the one that can simulate the view of adversary \( A \) by using functionality \( F \) only, constructing the ideal experiment. The proposed scheme is proved secure once the two experiments are indistinguishable.

**Theorem 1.** Our scheme is secure against an honest-but-curious probabilistic polynomial time (PPT) adversary under the COA model. The security strength depends on the image size, and the number of permutations in \( ImgValKey \).

**Proof.**

- **Security of image content.** As the Fig. 4 the simulator \( S \) simulates a set of images \( T^{S} \), and the corresponding identity set \( IID^{S} \) according to the storage leakage as shown in Fig. 4. The simulator \( S \) knows the total
The mainly ideal functionality $\mathcal{F}$ of our scheme as well as the corresponding information leakages.

(i) $\mathcal{F}$.\texttt{StoreImage}(I, UID, IID, $K_p$, $K_v$):

- **Functionality.** Each image owner encrypts all his images in $I$, and generates a set of encrypted images $C$. Next, each image owner uploads $C$, UID, IID to the CS.

- **Storage leakage.** The information leaked here includes $C$, IID, UID and the size of each images. What's more, the CS know the corresponding blocks are encrypted by the same valuesubstitution table.

(ii) $\mathcal{F}$.\texttt{Union}(OID, GID, $\{\text{IncValKey}\}$):

- **Functionality.** Image owners union as a group, and sends the IncValKey to the CS.

- **Relation leakage.** The information leaked here includes the OID in the same group, and the increment key itself. What's more, the CS can compute the difference of ImgValKey belong to the owner in the same group.

(iii) $\mathcal{F}$.\texttt{IndexGen}(C, UID, IID, GID):

- **Functionality.** CS extracts local histograms from images blocks belong to each image owner, and constructs the vocabulary by cluster algorithm, and calculates the feature vectors for each image in $C$ based on the corresponding UID and GID like Table 2.

- **Feature leakage.** The information leaked here includes the encrypted local histograms, the similarities and distributions of local histograms belong to the same source.

(iv) $\mathcal{F}$.\texttt{Query}($\{I_q, UID, GID\}$):

- **Functionality.** Authorized user encrypts the query image, and submits the encrypted images to cloud server as trapdoor. The CS execute the similarity calculation, and get the $\{IID\}$ of similar image, and ask KMC the corresponding decryption key. The CS finally return all the $\{UID/GID, C, EncImgPosKey\}$ to querier.

- **Query leakage.** The information leaked here includes the encrypted query images and the similarity between the encrypted images from the same image is also leaked.

Fig. 4: The functionality $\mathcal{F}$ and the information leakage in our framework

| Image Identity | OwnerOID | Feature vector aggregated from $(r,v)$ pairs for different authorized users | GlobalOID | GroupGID | GlobalGID |
|----------------|----------|--------------------------------------------------------------------------------|-----------|----------|-----------|
| IID(C)         | $f_{CID}^0 = (f_{1CD}^0)_{j=1}^{oid}$ | $f_{ID}^0 = (f_{1ID}^0)_{j=1}^{vid}$ | $f_{GID}^0 = (f_{1GID}^0)_{j=1}^{vid}$ | $f_{CID}^1 = (f_{1CID}^1)_{j=1}^{vid}$ | $f_{ID}^1 = (f_{1ID}^1)_{j=1}^{vid}$ | $f_{GID}^1 = (f_{1GID}^1)_{j=1}^{vid}$ |
| ...            | ...      | ...                                                                            | ...       | ...      | ...       |
| IID(C)         | $f_{CID}^0 = (f_{1CD}^0)_{j=1}^{oid}$ | $f_{ID}^0 = (f_{1ID}^0)_{j=1}^{vid}$ | $f_{GID}^0 = (f_{1GID}^0)_{j=1}^{vid}$ | $f_{CID}^1 = (f_{1CID}^1)_{j=1}^{vid}$ | $f_{ID}^1 = (f_{1ID}^1)_{j=1}^{vid}$ | $f_{GID}^1 = (f_{1GID}^1)_{j=1}^{vid}$ |
| ...            | ...      | ...                                                                            | ...       | ...      | ...       |
| IID(C)         | $f_{CID}^0 = (f_{1CD}^0)_{j=1}^{oid}$ | $f_{ID}^0 = (f_{1ID}^0)_{j=1}^{vid}$ | $f_{GID}^0 = (f_{1GID}^0)_{j=1}^{vid}$ | $f_{CID}^1 = (f_{1CID}^1)_{j=1}^{vid}$ | $f_{ID}^1 = (f_{1ID}^1)_{j=1}^{vid}$ | $f_{GID}^1 = (f_{1GID}^1)_{j=1}^{vid}$ |

TABLE 2: Partial linear index built for one image owner

- number of images and the size of each image. However, $S$ can only fill the images with the randomly generated pixels. As stated above, JPEG-format images are mainly consisted by the $DC$ values and $(r,v)$ pairs, both of which are contained in all $Y,U,V$ components. In our scheme, the above information is protected respectively by the substitutions and random permutations with different keys. The $v$ information between the real images and simulated ones are indistinguishable according to the property of random permutation. For a random permutation with length of 20, the computational complexity of a distinguisher $D$, executed by $S$, in distinguishing the color values is $20!$ because $D$ needs to figure out the correct one from $20!$ permutations, which means $\log_2(20!) \approx 61$ bits security strength. The information of $r$ is protected by block permutation and intra-block permutation. The security strengths of block permutation and intra-block permutation are equal to $\log_2(blknum_1)$ and $\log_2(blksize_1)$ bits, respectively. The $DC$ values is protected by the substitutions and bitxor by a random bit-stream. The security strengths of bitxor are equal to $n$, where $n$ means the length of random bit-stream. The image content is made up of all of these information and hence the security strength of image encryption $Sec_{Img}$ in our scheme can be calculated as:

$$
Sec_{Img} = 3 \times N_{prot1} \times \log_2(20!) + \sum \log_2(blknum_1) + 3 \times \sum \sum log_2(blksize_1) + 3 \times N_{prot2} \times \log_2(10!) + \sum \sum n_i(bits)
$$

- **Security of features.** In our scheme, image features are mainly calculated from the local histograms of
encrypted DC and \((r, v)\) pairs. With a simulated image \(S\), \(S\) can calculate the local histograms of the simulated image. The computational complexity of a distinguisher \(D\) in distinguishing the histogram is \(3 \times N_{pmt1} \times \log_2(20!) + 3 \times N_{pmt2} \times \log_2(10!)\) which means about 642 bits security strength if we set \(N_{pmt1} = N_{pmt2} = 5\).

- Security of query image and feature. As algorithm 6 shows, all queries are encrypted by different ImgPosKey and ImgValKey. The one-time pad encryption makes the multiple \(C\) the same security level with single one. As the query is firstly encrypted like algorithm 6, which makes the security of query not less than images in CS. What’s more, the extra BlockPerm avoids the leakage of relation between the encrypted blocks.

The images are encrypted by the combination of block permutation, intra-block permutation, value substitution and bittor in JES-MSIR. Although the security is partly depending on the image size, the efficiency advantage makes this kind of encryption more suitable for images compare to the methods based on HE [22].

### 6.1.2 Security under KBA model

In the KBA model, besides the information leakage defined in Fig. 4, the adversary also knows certain statistical properties of natural images, which degrades the security strength in Fig. 4, the adversary also knows certain statistical properties of natural images, which degrades the security strength in Fig. 4. For example, as illustrated in the first subfigure of Fig. 5, \(v\) values do not occur uniformly, and the small \(v\) value generally has much higher frequency. After substitution with a single table, the histogram bins have been shuffled, which protects the image statistical features to some extent. However, the distribution statistics are still reserved as shown in the second subfigure of Fig. 5, which decreases the computational complexity to figure out the secret permutation. In our scheme, the polyalphabetic cipher is utilized to encrypt the pixel values, which will flatten the \(v\) value histogram of the encrypted image and thus offering stronger security. Although the histogram become flatter, the size relation of retrieval distance are approximate kept. It is clearly a trade-off between the security and retrieval accuracy. In this paper, we set \(N_{pmt1} = N_{pmt2} = 5\).

### 6.2 Security under Collusion

In the above analysis, we prove our scheme is safe if each participant in the system is reliable. However, a reasonable system should be robust to the collusion between users. As the image stored in CS, we skip the analysis of collusion between KMC and member in group or user.

#### 6.2.1 The collusion between CS and KMC

Colluding CS and KMC own the knowledge of the encrypted images and encrypted key. The security of encrypted images has been shown in COA model, here we further prove KMC can not infer the ImgPosKey from encrypted keys.

As formula 1 shows, to the EncPerm and DecPerm, there are \(n!\) possible permutations for \(n\) elements. It means if all \(K, K_1, K_2\) are unknown, it is indistinguishable to infer them from the DecPerm\((K_2, K_1)\) and EncPerm\((K_1, K)\) only. Here the ImgPosKey is unknown as subsection 6.1. UserKey\(\text{OID}\) are kept in the owner side, and UserKey\(\text{UID}\) are stored in the authorized user side. As both CS and KMC are unfamiliar to the above information, it is difficult for them to infer ImgPosKey\(\text{OID,UID}\) from UserKey\(\text{OID,UID}\) and ImgPosKey\(\text{OID,UID}\). In an ideal environment (i.e. non-collusion), the CS and KMC can be undertaken by one server.

#### 6.2.2 The collusion between CS and authorized users

Colluding CS and AU have the knowledge of known decrypted images and ImgValKey\(\text{OID}\), which means the features are exposed. However, the images stored in CS are encrypted one-time pad ImgPosKey, in this case, the colluder can’t obtain the unknown images. As the features of owner is meaningless to authorized users, it will further decrease the possibility of collusion.

#### 6.2.3 The collusion between CS, KMC and a separate image owner

The image owner may try to know more images from other image owners through colluding with the CS. As different owner use different ImgValKey, we here mainly consider the potential colluding risk on the AU who authorized by conspirator and other image owners.

As Algorithm 7 shows, each encrypted query is finally protected by BlockPerm, which means the conspirator can
not get the block relation between the queries. Take $v$ for instance, as we use multi-table in the ValueSubstitution, which means each block may be encrypted by $N_{\text{pmt2}}$ possibilities. The owner can not infer the plaintext query feature in that there are $(N_{\text{pmt2}})^{\text{blknum}}$ possibilities for a image which has $\text{blknum}$ blocks. It further means the collusion with one image owner will not expose $\text{ImgValKey}$ of the image owners authorized to the same user. As KMC has no information related to $\text{ImgValKey}$, this kind of collusion will not leak the plaintext image.

6.2.4 The collusion between CS and member in the group

After collusion, CS has the knowledge of $\text{ImgValKey}_{\text{GID}}$ and $\text{UserKey}_{\text{GID}}$, which makes the image feature belong to the group exposed. However, as the $\text{ImgPosKey}$ is one-time-pad, it can not be directly exposed. Further, the key KMC sends to CS is encrypted by AES if it corresponding to a group, which means CS actually has no information related to $\text{UserKey}_{\text{GID}}$. So the position information of image is still secure in this situation.

6.3 The security comparison

Here we compare the security with the former paper from the respective of image content and image feature, and the conclusion can be seen in table 5. In [5], to avoid the key conversion during image decryption, the KMC decrypts and gets the plaintext image, which makes their scheme insecure. In [4], the feature security depends on a global key, which can be got by colluding CS and KMC.

7 EXPERIMENT RESULTS

The section evaluates the performance of the proposed scheme in terms of encryption effectiveness, retrieval accuracy and efficiency. We implement the proposed scheme with Matlab 2018a on a Windows 10 operation system. All the experiment in the user side (i.e. source and authorized user) are executed in an machine with Intel Core i5-8250u CPU @ 1.6GHZ and 16GB memory. The experiment in the Cloud side (i.e. CS or KMC) are executed on a machine with Intel Core i7-6900K CPU @ 3.20GHz and 64 GB memory. We firstly use the common used Corel-1k image dataset [43] as the experiment dataset. The images in this dataset size either $384 \times 256$ or $256 \times 384$. The image dataset includes 10 categories of images and each category contains 100 similar images.

7.1 Upload/Update consumption

In this section, we focus on the time consumption in the image owner side. Generally speaking, in the existing schemes, the image owner needs to execute the following sub-operation: Image encryption, Feature extraction, Feature aggregation, Feature encryption. The time consumption comparison on uploading Corel-1k dataset is shown in Table 4. Benefiting from the simple encryption scheme, the [5] and [6] is in high efficiency. Suffering from the high computation complexity of FHE, the encryption on feature is also an expensive operation in [4].

Further, the image owner have the need for updating their image. The existing schemes execute the following sub-operation during update: Image update, Feature update. The time consumption in update is shown as Table 5. The update operation in [3], [5], [6], and JES-MSIR is similar with the uploading. In [4], the image owner only needs to generate the feature based on existing visual words. However, it still leads to a costly update.

The time consumption of transferring the image to the CS and the following operation on the encrypted images is almost linear to the size of encrypted image, we further give the size of encrypted image information in Table 6. The size of encrypted image in [3], [4] are equal to plaintext. Fig. 6 illustrates the separate and joint effect of the three protecting steps. It should be noticed that the multiple permutations leads to more uniform encrypted pixels.

![Image](image.png)

Fig. 6: The visual effect of encryption, (a) the original image (133.jpg in Corel-1k database), the size of which is $384 \times 256$, (b) with block permutation only, (c) with intra-block permutation only, (d) with value substitution only, (e) with value substitution under $N_{\text{pmt1}} = 1$, (f) with value substitution under $N_{\text{pmt1}} = 2$.

7.2 Retrieval Consumption and Precision

In our experiments, the “precision” for a query is defined as that in [44]: $P_m = m'/m$, where $m'$ is the number of real similar images in the $m$ retrieved images. We choose all 10 categories to test the retrieval precision and time consumption.

7.2.1 single-source

During the retrieval, the time consumption are composed by three part: Trapdoor generation, similarity consumption in cloud side, decryption. The time consumption comparison on retrieval(return Top-50 similar images) is shown as Table 7. Due to the leakage of index, the similarity computation in [6] is
TABLE 3: Security comparison

| JES-MSIR | MIPP [3] | PIC [4] |
|----------|----------|---------|
| No Collusion | yes | yes | yes |
| Colluding CS and KMC | yes | no | yes |
| Colluding CS and Owner | yes | no | yes |
| Colluding CS and separate Owner | yes | no | yes |
| Colluding CS and member | yes | no | - |

TABLE 4: Time consumption of image dataset upload

| JES-MSIR | Cheng [6] | IES-CBIR [5] | MIPP [3] | PIC [4] |
|----------|----------|-------------|---------|---------|
| Image encryption | 90.1s | 97.07s | 47.66s | 2.51s |
| Feature extraction | - | - | - | 13s |
| Feature aggregation | - | - | - | - |
| Feature encryption | - | - | - | 6.7s |
| Total time consumption | 90.1s | 79.07s | 47.66s | 22.21s |

TABLE 5: Time consumption of image update

| JES-MSIR | Cheng [6] | IES-CBIR [5] | MIPP [3] | PIC [4] |
|----------|----------|-------------|---------|---------|
| Image update | 0.09s | 0.08s | 0.03s | 0.05s |
| Feature update | - | - | - | 0.02s |
| Total time consumption | 0.09s | 0.08s | 0.03s | 0.05s |

TABLE 6: The size increment of the encrypted image dataset

| Corel-1k dataset | Plaintext | JES-MSIR | Cheng [6] | IES-CBIR [5] |
|------------------|-----------|----------|----------|-------------|
| Corel-1k dataset | 32.3MB | 57.1MB | 40.5MB | 268MB |

Fig. 7: Retrieval accuracy comparison in Corel-1k dataset

7.2.2 multi-source

To better show the result in multi-source scene, Corel-10k image dataset [46] are utilized in multi-source scene. This image database includes 100 categories of images and each category contains 100 similar images. The size of image is either 187 × 126 or 126 × 187. We choose all 100 categories to test the retrieval precision and time consumption. In our experiment, the images in Corel-10k dataset are randomly distributed to each image owner, and all the image owners possess the whole 10,000 images.

The retrieval time consumption are similar to the situation in single-source. Although our scheme needs to encrypt multiple queries, however, the time of trapdoor generation is far less than the other steps. Specially, the interaction rounds during the retrieval are shown in TABLE 8. The interaction between CS and KMC in [4] is unsure in that they can not ensure two rounds of interaction can search enough similar images.

Figure. 8 uses the Corel-10k database shows the retrieval accuracy comparison in the single-source scene. When N source (i.e. the number of source) increases, the accuracy of [3] will kept same as the feature they use kept same; the accuracy of [4] will have an extent of change as the image owners jointly maintain the same codebook. When the images significantly increase, the quality of codebook will infect the accuracy, the influence is basically same as the plaintext image retrieval [47]. It should be noticed it is unrobust as the alternation of codebook needs the participation of image owners.

In JES-MSIR, as mentioned in subsection 4.3.4, the distance are still in the same level if the same number of cluster centers are chosen. To choose reasonable k_g for the system, we firstly use grid search to choose the approximately optimal k_grid for the 1-source (k_V = 200, k_U = 50, k_V = 50).
TABLE 7: Time consumption of retrieval (Top-50)

|                         | JES-MSIR | Cheng [6] | IES-CBIR [5] | MIPP [3] | PIC [4] | Trapdoor generation | Similarity computation in cloud | Decryption | Total time consumption |
|-------------------------|----------|-----------|--------------|----------|---------|---------------------|---------------------------------|------------|----------------------|
|                         | 0.18s    | 0.10s     | 0.11s        | 0.05s    | 0.03s   | >600s               | 75.63s                          | 600s       | >616.67s             |

Then we use the \( k_{grid} \) as the \( k_g \) to test the situation on different \( N_{source} \). Further, the two, ten, half, tenth times of \( k_{grid} \) are utilized as \( k_g \) to test the robustness.

As shown in Fig. 9 three conclusions can be seen. Firstly, the retrieval accuracy decrease in a slow speed in the same choice of cluster number. For instance, the retrieval accuracy (Top-50) only decrease 7.3% when \( N_{source} \) increase from 1 to 1,000. It means even in a extreme situation (i.e. each image owner has average 10 images), the retrieval accuracy still stable. And the decrease ratio is decline with the increment of returned images as shown in Fig. 10. Secondly, small increment of \( k \) is beneficial to accuracy. For instance, two times \( k_{grid} \) get better accuracy when \( N_{source} \) over 500. Last but not least, the change on \( k_g \) show little influence on the results. It should be noticed that only 10% accuracy loss when the 10 times \( k_{grid} \) in utilization. And the accuracy is still better than [4] even in extreme situation (i.e. \( k_Y = 20 \), \( k_U = 5 \), \( k_V = 5 \)).

As most of methods which can infer the \( k_{sug} \) need consume plenty of resources when the feature is huge. In this case, only part of feature are randomly chosen from the original feature as an optimization in our experiment, and the proportion of chosen feature can be briefly called ratio, where ratio \( \in (0, 1) \). Gap statics [38] method is employed in the experiment to get the \( k_{sug} \). A sublinear speed is gotten when the number of image decline. Consider all the above factors comprehensively, we here suggest the \( k_g \) chosen as \( k_{suggest} = \frac{1}{N_{source}}(\sum_{i=1}^{N_{source}} k_{sug}^{i}) \cdot \log_2(1 + \frac{1}{\text{ratio}}) \cdot \log_2(1 + N_{source}) \). The result is shown in Fig. 9 and Fig. 10. it could be noticed appropriate accuracy and slower decline can be got in different \( N_{source} \). What’s more, as all the index building is undertaken by CS, it is easy for CS to update the \( k_g \) at regular intervals.

![Fig. 8: Retrieval accuracy comparison in Corel-10k dataset](image1)

![Fig. 9: Top-50 accuracy comparison in different choice of \( k \)](image2)

![Fig. 10: Retrieval accuracy decrease ratio in different Top-m](image3)

8 Conclusion

In this paper, we introduce the multi-source privacy-preserving CBIR problem and propose a novel scheme which can effectively and securely cope with this problem. Different from the previous schemes which use the
homomorphic encryption, we propose our scheme based on the randomization encryption, which leads to a higher efficiency and acceptable accuracy and security. The bitxor and permutation are used to ensure the security of the image, and the BOW model is used to aggregate the encrypted \((r, v)\) pairs in multi-source scene. As the retrieval accuracy is still insufficient when compared with that in plaintext domain, in the future, we consider to execute the state-of-art CBIR scheme in safety based on two non-collusion CS.

ACKNOWLEDGEMENTS

This work is supported in part by the National Natural Science Foundation of China under grant numbers 61672294, 61502242, 61702276, U1536206, U1405254, 61772283, 61602253, 6101236, and 61572258, in part by Six peak talent project of Jiangsu Province (R2016L13), in part by the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD) fund, in part by NRF-2016R1D1A1B03933294, in part by the Jiangsu Basic Research Programs-Natural Science Foundation under grant numbers BK20150925 and BK20151530, in part by the Collaborative Innovation Center of Atmospheric Environment and Equipment Technology (CICAEET) fund, China. Zhihua Xia is supported by BK21+ program from the Ministry of Education of Korea.

REFERENCES

[1] L. Zheng, Y. Yang, and Q. Tian, “Sift meets cnn: A decade survey of instance retrieval,” IEEE transactions on pattern analysis and machine intelligence, vol. 40, no. 5, pp. 1224–1244, 2017.
[2] C. D. Manning, P. Raghavan, and H. Schütze, Introduction to information retrieval. Cambridge university press, 2008.
[3] M. Shen, G. Cheng, L. Zhu, X. Du, and J. Hu, “Content-based multi-source encrypted image retrieval in clouds with privacy preservation,” Future Generation Computer Systems, 2018.
[4] L. Zhang, T. Jung, K. Liu, X.-Y. Li, X. Ding, J. Gu, and Y. Liu, “Pic: Enable large-scale privacy-preserving content-based image search on cloud,” IEEE Transactions on Parallel and Distributed Systems, vol. 28, no. 11, pp. 3288–3271, 2017.
[5] B. Ferreira, J. Rodrigues, J. Leitao, and H. Domingos, “Practical privacy-preserving content-based retrieval in cloud image repositories,” IEEE Transactions on Cloud Computing, 2017.
[6] H. Cheng, X. Zhang, J. Yu, and Y. Zhang, “Encrypted jpeg image retrieval using block-wise feature comparison,” Journal of Visual Communication and Image Representation, vol. 40, pp. 111–117, 2016.
[7] X. Zhang and H. Cheng, “Histogram-based retrieval for encrypted jpeg images,” in 2014 IEEE China Summit & International Conference on Signal and Information Processing (ChinaSIP). IEEE, 2014, pp. 446–449.
[8] W. Lu, A. L. Varna, and M. Wu, “Confidentiality-preserving image search: a comparative study between homomorphic encryption and distance-preserving randomization,” IEEE Access, vol. 2, pp. 125–141, 2014.
[9] W. Lu, A. Swaminathan, A. L. Varna, and M. Wu, “Enabling search over encrypted multimedia databases,” in Media Forensics and Security, vol. 7254. International Society for Optics and Photonics, 2009, p. 725416.
[10] W. Lu, A. L. Varna, A. Swaminathan, and M. Wu, “Secure image retrieval through feature protection,” in 2009 IEEE International Conference on Acoustics, Speech and Signal Processing. IEEE, 2009, pp. 1533–1536.
[11] Z. Xia, Y. Zhu, X. Sun, Z. Qin, and K. Ren, “Towards privacy-preserving content-based image retrieval in cloud computing,” IEEE Transactions on Cloud Computing, vol. 6, no. 1, pp. 276–286, 2015.
[12] D. G. Lowe, “Object recognition from local scale-invariant features,” in Proceedings of the seventh IEEE international conference on computer vision, vol. 2. Ieee, 1999, pp. 1150–1157.
[13] Y. Rubner, C. Tomasi, and L. J. Guibas, “The earth mover’s distance as a metric for image retrieval,” International journal of computer vision, vol. 40, no. 2, pp. 99–121, 2000.
[14] J. Yuan, S. Yu, and L. Guo, “Seisa: Secure and efficient encrypted image search with access control,” in 2015 IEEE conference on computer communications (INFOCOM). IEEE, 2015, pp. 2083–2091.
[15] W. K. Wong, D. W.-l. Cheung, B. Kao, and N. Mamoulis, “Secure knn computation on encrypted databases,” in Proceedings of the 2009 ACM SIGMOD International Conference on Management of data, 2009, pp. 139–152.
[16] J. Shashank, P. Kowshik, K. Srinathan, and C. Jawahar, “Private content based image retrieval,” in 2008 IEEE Conference on Computer Vision and Pattern Recognition. IEEE, 2008, pp. 1–8.
[17] P. Zheng and J. Huang, “An efficient image homomorphic encryption scheme with small ciphertext expansion,” in Proceedings of the 21st ACM international conference on Multimedia, 2013, pp. 803–812.
[18] P. Paillier, “Public-key cryptosystems based on composite degree residuosity classes,” in International conference on the theory and applications of cryptographic techniques. Springer, 1999, pp. 223–238.
[19] C. Gentry, “Fully homomorphic encryption using ideal lattices,” in Proceedings of the forty-first annual ACM symposium on Theory of computing, 2009, pp. 169–178.
[20] C.-Y. Hsu, C.-S. Lu, and S.-C. Pei, “Image feature extraction in encrypted domain with privacy-preserving sift,” IEEE transactions on image processing, vol. 21, no. 11, pp. 4993–4607, 2012.
[21] M. Schneider and T. Schneider, “Notes on non-interactive secure comparison in’ image feature extraction in the encrypted domain with privacy-preserving sift’,” in Proceedings of the 2nd ACM workshop on Information hiding and multimedia security, 2014, pp. 135–140.
[22] S. Hu, Q. Wang, J. Wang, Z. Qin, and K. Ren, “Securing sift: Privacy-preserving outsourcing computation of feature extractions over encrypted image data,” IEEE Transactions on Image Processing, vol. 25, no. 7, pp. 3411–3425, 2016.
[23] Q. Wang, S. Hu, K. Ren, J. Wang, Z. Wang, and M. Du, “Catch me in the dark: Effective privacy-preserving outsourcing of feature extractions over image data,” in IEEE INFOCOM 2016-The 35th Annual IEEE International Conference on Computer Communications. IEEE, 2016, pp. 1–9.
[24] F. Liu, Y. Wang, F.-C. Wang, Y.-Z. Zhang, and J. Lin, “Intelligent and secure content-based image retrieval for mobile users,” IEEE Access, vol. 7, pp. 119,209–119,222, 2019.
[25] Z. Xia, L. Jiang, D. Liu, L. Lu, and B. Jeon, “Boe: a content-based image retrieval scheme using bag-of-encrypted-words in cloud computing,” IEEE Transactions on Services Computing, 2019.
[26] H. Liang, X. Zhang, and H. Cheng, “Huffman-code based retrieval for encrypted jpeg images,” Journal of Visual Communication and Image Representation, vol. 61, pp. 149–156, 2019.
[27] J. Gong, Y. Xu, and X. Zhao, “A privacy-preserving image retrieval method based on improved bow model in cloud environment,” IETE Technical Review, vol. 35, no. sup1, pp. 76–84, 2018.
[28] Y. Xu, J. Gong, L. Xiong, Z. Xu, J. Wang, and Y.-q. Shi, “A privacy-preserving content-based image retrieval method in cloud environment,” Journal of Visual Communication and Image Representation, vol. 43, pp. 164–172, 2017.
[29] T. Jung, X.-Y. Li, and M. Wan, “Collusion-tolerable privacy-preserving sum and product calculation without secure channel,” IEEE Transactions on Dependable and secure computing, vol. 12, no. 1, pp. 45–57, 2014.
[30] L. Xiao, O. Bastani, and I.-L. Yen, “An efficient homomorphic encryption protocol for multi-user systems.” IACR Cryptology ePrint Archive, vol. 2012, p. 193, 2012.
[31] G. Schaefer, “Fast compressed domain jpeg image retrieval,” in 2017 International Conference on Vision, Image and Signal Processing (ICVISP). IEEE, 2017, pp. 22–26.
[32] A. K. Jain and A. Vailaya, “Image retrieval using color and shape,” Pattern recognition, vol. 29, no. 8, pp. 1233–1244, 1996.
[33] J. Sivic and A. Zisserman, “Video google: A text retrieval approach to object matching in videos,” in null. IEEE, 2003, p. 1470.
[34] G. Chen, Y. Mao, and C. K. Chui, “A symmetric image encryption algorithm using dna sequence operations,” Chaos, Solitons & Fractals, vol. 238, 2009, pp. 749–761, 2004.
[35] X. Chai, Y. Chen, and L. Brody, “A novel chaos-based image encryption algorithm using dna sequence operations,” Optics and Lasers in engineering, vol. 88, pp. 197–213, 2017.
[36] G. Schaefer, “Jpeg image retrieval by simple operators,” 2001.
[37] D. Pelleg, A. W. Moore et al., “X-means: Extending k-means with efficient estimation of the number of clusters.” in Icml, vol. 1, 2000, pp. 727–734.

[38] R. Tibshirani, G. Walther, and T. Hastie, “Estimating the number of clusters in a data set via the gap statistic,” Journal of the Royal Statistical Society: Series B (Statistical Methodology), vol. 63, no. 2, pp. 411–423, 2001.

[39] O. Chum, J. Philbin, A. Zisserman et al., “Near duplicate image detection: min-hash and tf-idf weighting.” in BMVC, vol. 810, 2008, pp. 812–815.

[40] M. Muja and D. G. Lowe, “Scalable nearest neighbor algorithms for high dimensional data,” IEEE transactions on pattern analysis and machine intelligence, vol. 36, no. 11, pp. 2227–2240, 2014.

[41] J. Daemen and V. Rijmen, “Rejindael: The advanced encryption standard.” Dr. Dobb’s Journal: Software Tools for the Professional Programmer, vol. 26, no. 3, pp. 137–139, 2001.

[42] R. Canetti, “Universally composable security: A new paradigm for cryptographic protocols,” in Proceedings 42nd IEEE Symposium on Foundations of Computer Science. IEEE, 2001, pp. 136–145.

[43] J. Li and J. Z. Wang, “Automatic linguistic indexing of pictures by a statistical modeling approach,” IEEE Transactions on pattern analysis and machine intelligence, vol. 25, no. 9, pp. 1075–1088, 2003.

[44] H. Müller, W. Müller, D. M. Squire, S. Marchand-Maillet, and T. Pun, “Performance evaluation in content-based image retrieval: overview and proposals,” Pattern recognition letters, vol. 22, no. 5, pp. 593–601, 2001.

[45] “http://lear.inrialpes.fr/~jegou/holidays_state_of_art.html.”

[46] J. Z. Wang, J. Li, and G. Wiederhold, “Simplicity: Semantics-sensitive integrated matching for picture libraries,” IEEE Transactions on pattern analysis and machine intelligence, vol. 23, no. 9, pp. 947–963, 2001.

[47] F. Chierichetti, A. Panconesi, P. Raghavan, M. Sozio, A. Tiberi, and E. Upfal, “Finding near neighbors through cluster pruning,” in Proceedings of the twenty-sixth ACM SIGMOD-SIGACT-SIGART symposium on Principles of database systems, 2007, pp. 103–112.

Qi Gu is currently pursuing his master degree in the School of Computer and Software, Nanjing University of Information Science and Technology, China. His research interests include functional encryption, image retrieval and nearest neighbor search.

Zhihua Xia received his B.S. degree in Hunan City University, China, in 2006, and the Ph.D. degree in computer science and technology from Hunan University, China, in 2011. He is currently an associate professor with the School of Computer and Software, Nanjing University of Information Science and Technology, China. He was a visiting professor with the Sungkyunkwan University, Korea, 2016. His research interests include cloud computing security and digital forensics. He is a member of the IEEE.

Xingming Sun received his BS in mathematics from Hunan Normal University, China, in 1984, MS in computing science from Dalian University of Science and Technology, China, in 1988, and PhD in computing science from Fudan University, China, in 2001. He is currently a professor in China-USA Computer Research Center, China. His research interests include network and information security, digital watermarking, and data security in cloud.

Jian Weng received the B.S. and M.S. degrees in computer science and engineering from South China University of Technology, Guangzhou, China, in 2000 and 2004, respectively, and the Ph.D. degree in computer science and engineering from Shanghai Jiao Tong University, Shanghai, China, in 2008. From 2008 to 2010, he held a Postdoctoral position with the School of Information Systems, Singapore Management University. He is currently a Professor and the Dean with the College of Information Science and Technology, Jinan University, Guangzhou, China. He has authored or coauthored more than 100 papers in cryptography and security conferences and journals, such as CRYPTO, EUROCRYPT, ASIACRYPT, TCC, PKC, TPAMI, TIFS, and TDSC. His research interests include public key cryptography, cloud security, and blockchain. He was the PC Co-Chairs or PC Member for more than 30 international conferences. He also serves as an Associate Editor for the IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY.