Content-based image and video analysis

Copy/Near Duplicate Detection

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05.07.2009
What is a copy/near-duplicate?

Near-duplicate image:

An image is called a near-duplicate of a reference image if it is “close”, according to some defined measure, to the reference image.

Another definition:

An image that appears, to a human observer, to be identical or very similar.

Near duplicate image cases:

• Being perceptually identical
• Being images of the same 3D scene
Copy / Similarity

The Robustness issue:
Two videos which are copies
Source video: *Système deux*. C. Fayard 1975 (c)INA

The Discriminability issue:
Two similar videos which are not copies (different ties)
Applications

- Detection of copyright violations
- Detection of doubles in large image databases
  - Reduction of required disk space
- Grouping images in search results
- Commercial tracking
- Compression of video files
Sample application

Results for the query “flight of a bee” using Google Image Search

Greater diversity of images on the results first page
- Video Copy Detection: a Comparative Study

- Julien Law-To, Li Chen, Alexis Joly, Ivan Laptev, Olivier Buisson, Valerie Gouet-Brunet, Nozha Boujemaa, Fred Stentiford
Global Descriptors

- **Temporal**

  \[ a(t) = \sum_{i=1}^{N} K(i)(I(i, t) - I(i, t - 1))^2 \]

  - \( a(t) \): global temporal activity, \( I \): image, \( N \): number of pixels for each image, \( K(i) \): weight function to enhance the importance of the central pixels

  - A signature is computed around each maxima of the temporal activity \( a(t) \)

  - Spectral analysis by FFT leads to a 16-dimensional vector based on the phase of the activity.
Global Descriptors II

- **Ordinal Measurement**
  - Partition the image into N blocks
  - Sort the blocks using their average gray level
  - Signature $S(t)$ uses the rank $r_i$ of each block $I_i$
    \[ S(t) = (r_1, r_2, \ldots, r_N) \]
  - The distance $D(t)$ is defined for computing the similarity of two videos (a reference $R$ and a candidate $C$) at a time $t$ where $T$ is the length of the considered segment.
    \[ D(t) = \frac{1}{T} \sum_{i=t-T/2}^{t+T/2} |R(i) - C(i)| \]
Global Descriptors III

- **Temporal Ordinal Measurement**
  - Rank the regions along the time
  - Each frame is divided into \( K \) blocks, \( \lambda^k \) is the rank of the region \( k \) in a temporal window with the length \( M \).
  - The distance \( D \) between a query video \( V_q \) and a reference video \( V_r \) at the time \( t \) is:
    \[
    D(V_q, V_r^p) = \frac{1}{K} \sum_{k=1}^{K} d^p(\lambda_q^k, \lambda_r^k)
    \]
    where,
    \[
    d^p(\lambda_q^k, \lambda_r^k) = \frac{1}{C_M} \sum_{i=1}^{M} |\lambda_q^k(i) - \lambda_r^k(p + i - 1)|
    \]
    \( p \) is the temporal shift tested and \( C_M \) is a normalizing factor. The best temporal shift \( p \) is selected.
Local Descriptors: AJ

- Key-frame detection \((X, Y\text{ image dimensions})\)
  \[
a(t) = \frac{\sum_{x=1}^{X} \sum_{y=1}^{Y} |I(x, y, t + 1) - I(x, y, t)|}{XY}
\]

- An interest point detection
  - An improved version of the Harris interest point detector

- Computation of local differential descriptors around each interest point:
  \[
f = \left( \frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}, \frac{\partial I}{\partial x\partial y}, \frac{\partial^2 I}{\partial x^2}, \frac{\partial^2 I}{\partial y^2} \right)
\]

- Computed at four different spatio-temporal positions distributed around the interest point making in total \(5 \times 4 = 20\)-dimensional fingerprint \(F\)
Local Descriptors: ViCopT

- **Harris** interest points are extracted on every frame.
- Signal description similar to the one used in **AJ** is computed.
- The local differential descriptors are extracted at four spatial positions around an interest point, leading to 20-dimensional signatures for each frame.
- The interest points are associated from frame to frame to build trajectories.
- For each trajectory, the signal description is the average of each component of the local description.
- A label is also assigned to local descriptions: Background & Motion
Local Descriptors: **STIP**

- **STIP**: Space Time Interest Points
- STIP correspond to points where the image values have significant local variation in both space and time.

STIP points are described by the spatio-temporal third order local jet leading to a 34-dimensional vector.

\[ j = (L_x, L_y, L_t, L_{xx}, \ldots, L_{ttt}) \]
Evaluation

- BBC open news archives. 79 videos (~3.1 hours)

- Performance measures: Precision, recall, average precision
Single Transformations

- Exact Copy
- Contrast 75
- Contrast 125
- Crop
- Blur
- Letter-box
- Insert
- Zoom 1.2
- Zoom 0.8
Outcomes

- For all transformations, **Temporal Ordinal Measure** presents excellent results: all the segments have been found with no false alarm.
- The **Ordinal Measure** presents poor results for zooming, cropping and letter-box transformations.
- Local descriptors based on Harris points of interest are not robust to a decrease of the contrast because the value of the corners can become too low.
Combined Transformations

(a) Source video: hkyachtclub (c)BBC

(b) Source video: sheepclone (c)BBC.

(c) Source video: manhattanaftermath (c)BBC.
Results

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<thead>
<tr>
<th>Technique</th>
<th>AveP</th>
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<tr>
<td>ViCopT</td>
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<tr>
<td>Ord. Meas.</td>
<td>0.36</td>
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</table>

Content-based image and video retrieval
- Scalable Near Identical Image and Shot Detection
  O. Chum, J. Philbin, M. Isard, A. Zisserman

- Credit: Michael Weber
Tasks

- Enumeration of duplicates in a corpus
  - Given
    - Set of images
    - Query image
  - Wanted
    - Corpus with all duplicate images

- Identification of a duplicate image
  - Given
    - Set of images
    - Query image
  - Wanted
    - Pruned list from the top matches
Problems

- Partial occlusion
- Digitalization artifacts
- Compression artifacts
- Differing levels of compression
- Mild photometric distortions
- Image blur
Copy Duplicate Detection Methods

Color Histograms & LSH
- Color Histograms
- Locality Sensitive Hashing

SIFT Features & Min Hash
- SIFT Features
- Min Hash

Requirements in large databases
- Small amount of data stored for each image
- Queries must be very fast

• Both presented methods achieve these requirements
Color Histograms & LSH

**Color Histograms**
- Used for image representation
  - Extremely compressed feature vector
  - Stored information size per image is 384 bytes

**Locality Sensitive Hashing**
- Used to find near duplicate histograms
  - Efficiently finds all points within a given radius with high probability
- Euclidean distance between feature vectors is used as measure of similarity
Color Histograms I

Opponent color model

- Simple to compute
- 3 channels $I$, $O_1$ and $O_2$

\[
I = (R + G + B) / 3
\]

\[
O_1 = (R + G - 2B) / 4 + 0.5
\]

\[
O_2 = (R - 2G + B) / 4 + 0.5
\]
Color Histograms II

Spatial pyramid scheme

- Jointly encodes global and local information
- 3 levels of data – every level has 128 bytes
- The higher the level, the more local the data
- I has double the amount of data as $O_1$ and $O_2$ because more information is contained in the intensity information
- Each bin is represented by a single byte

<table>
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<th>$O_2$</th>
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Locality Sensitive Hashing

- Hashes similar histograms into same bins
- Several hashing functions are used because of boundary effects

Index Building
- Builds a family of hashing functions
- Hashes every image vector from the database into the hash tables of all hash functions

Query Processing
- Hashes the query vector into every hash table
- Points in the same bins of the hash tables are the near duplicate images
Color Histograms & LSH Summary

- Creates a p-dimensional vector \( v \) from the color histogram
- Each hashing function from locality sensitive hashing generates an integer hash value from \( v \)
- All images in the database have to be hashed this way into the hash tables
- For queries only the hash values have to be calculated and searched in the hash tables
SIFT Features & Min Hash

Image description
- SIFT features are used for image representation
  - Robust and insensitive to small local distortions
- Visual words are used because Min Hash was developed for text near duplicate detection

Min Hash
- Used to find images whose similarity is above a given threshold for a given query
- Used in this method because the feature vectors do not have to be as similar as in LSH
- Finds similar images in constant time
SIFT Features

- **Scale Invariant Feature Transform (SIFT)**
  - Transformation of image data into scale-invariant coordinates relative to local features
  - Insensitive to small local geometric and photometric image distortions

(a) Original image. (b) Image with SIFT features
Image Description

- Representation of feature regions by SIFT descriptors
- A visual vocabulary $\mathcal{V}$ - a set of visual words is constructed quantizing the SIFT features with K-means
- Each K-means cluster center is a visual word
- Visual words are used to compare images
- Each image is represented as a set $A_i$ of words $A_i \subseteq \mathcal{V}$
- Distance between two images: $\text{sim} (A_1, A_2) = \frac{|A_1 \cap A_2|}{|A_1 \cup A_2|}$
Min Hash

- Developed for text near duplicate detection
- Works with visual words
- Algorithm
  - Create random permutations \( \pi \)
  - For each document \( A_i \) a min hash \( \min_{\pi_j}(A_i) \) is recorded
- Estimation of \( \text{sim}(A_1, A_2) \):
  - \( \text{sim}(A_1, A_2) = \ell/N \)
  - \( N \) is the number of independent permutations \( \pi_j \)
  - \( \ell \) is the number of how many times \( \min_{\pi_j}(A_1) = \min_{\pi_j}(A_2) \)
Min Hash Example

Vocabulary $V = \{A, B, C, D, E, F\}$

Three sets $\{A, B, C\}$, $\{B, C, D\}$ and $\{A, E, F\}$

Estimated similarities

$\{A, B, C\}$ with $\{B, C, D\}$: $3/4$

$\{A, B, C\}$ with $\{A, E, F\}$: $1/4$

$\{A, E, F\}$ with $\{B, C, D\}$: $0/4$
SIFT Features & Min Hash summary

- Each feature region is represented by a SIFT descriptor
- K-means quantizes the SIFT descriptors of features to sets of visual words
- Min hash efficiently finds near duplicate images of a query image in the data set
- Similarity is computed using a set overlap measure
Experiment I – data set

TRECVID 2006 database

- 165 hours (17.8M frames, 127 GB) MPEG-1 news footage from different TV stations from all over the world
- For image detection taken 146,588 frames
- Resolution is 352x240 pixels
- Data is not labeled
- Frames contain
  - Compression artifacts
  - Jitter
  - Noise
Experiment I

- **True similarity set**
  - Images that match the similarity definition:
    - Images whose histograms are within a given distance to the reference histogram
    - Set of images whose similarity is above a threshold

- **Raw approximate similarity set**
  - Images found by
    - Using the reference histogram for LSH query
    - Having at least one matching tuple of visual words
  - Includes many false positives

- **Verified approximate similarity set**
  - Filtered version of the raw approximate similarity set
Experiment I - results

- Used parameters for verification
  - Histogram method
    - Distance < 200
  - Min hash method
    - Similarity > 35%
- Random pairs
  - In 99.9% of cases
    - Histogram method
      - Distance > 500
    - Min hash method
      - Similarity < 5%

Similarity for the Histogram method

Similarity for the Min hash method
Experiment I - results

<table>
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<tr>
<th>Method</th>
<th>False negatives</th>
<th>Ratio raw : verified approximates</th>
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<tbody>
<tr>
<td>Color Histograms &amp; LSH</td>
<td>0.98%</td>
<td>9.09</td>
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<tr>
<td>SIFT Features &amp; Min Hash</td>
<td>0.75%</td>
<td>10.04</td>
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</table>

Left: Raw approximate set
Middle: Verified approximate set
Right: False negatives
Above: Histogram method
Below: Min hash method
Experiment II

- Several selected sets of 30-40 near duplicate images from the TRECVID 2006 database

- Results
  - No false positives found (manual verification)
  - No exact knowledge about false negatives, but
  - Each method has a small number of false negatives compared with the other
Experiment II - results

Detected by both / Color Histograms & LSH only / SIFT Features & Min Hash only
Conclusions

Color Histograms & LSH
- Sensitive to occlusion
- Fairly insensitive to
  - Compression / digitalization artifacts
  - Noise
  - Image blur

SIFT Features & Min Hash
- Tolerates occlusion that preserve a sufficiently high percentage of visual words
- Sensitive to all deformations, increasing or decreasing the number of features like noise, Image blur and strong artifacts
TRECVID 2008 Content-based Copy Detection (CBCD)

- A pilot task with synthetic queries
- Audio handled in a separate condition
- Task has both a detection and localization component
- Detection measure based on error rates
- Weighted trade-off of false alarms and misses
CBCD Task Overview

- **Goal:**
  - Build a benchmark collection for video copy detection methods

- **Task:**
  - Given a set of reference video collection and a set of 2000 queries,
  - determine for each query if it contains a copy of video from the reference collection
  - and if so, from where in the reference collection the copy comes

- Three main task types were derived: Video-only, audio-only, video + audio
Datasets and Queries

- **Dataset:**
  - Reference video collection: TV2007 and TV2008 sound & vision data (~200 hr)
  - Non-reference video collection: TV2007 BBC rushes data

- **Query types:**
  - Type 1: composed of a reference video only. (1/3)
  - Type 2: composed of a reference video embedded in a non-reference video. (1/3)
  - Type 3: composed of a non-reference video only. (1/3)

- **Number of queries:**
  - 201 total original queries were created
  - 67 queries for each type
Datasets and Queries

- After creating the queries, each was transformed:
  - 10 video transformations
  - 7 audio transformations
- Yielding:
  - \(10 \times 201 = 2010\) video queries
  - \(7 \times 201 = 1407\) audio queries
  - \(10 \times 7 \times 201 = 14070\) audio+video queries
Video Transformations

- Cam Cording (T1)
- Picture in picture (T2)
- Insertions of pattern (T3)
- Strong re-encoding (T4)
- Change of gamma (T5)
- Decrease in quality (T6, T7) – by introducing a combination of Blur, Gamma, Frame dropping, Contrast, Compression, Ratio, White noise
  - For T6, 3 transformations are randomly selected and combined
  - For T7, 5 transformations are randomly selected and combined
Video Transformations

- Post production (T8, T9) – by introducing a combination of Crop, Shift, Contrast, Text insertion, Vertical mirroring, Insertion of pattern, Picture in picture,
  - For T8, 3 transformations are randomly selected and combined
  - For T9, 5 transformations are randomly selected and combined
- Combination of 5 randomly selected transformations chosen from T1-9 (T10)
Video Transformations Examples

- Picture in Picture
- Blur
- Insertion of pattern
- Strong re-encoding
- Noise
- Contrast
- Change in gamma
- Mirroring
- Ratio
- Crop
- Shift
- Text insertion

Content-based image and video retrieval
Sample Query Clips
Evaluation

- 22 participant teams
- 55 submitted runs (48 runs for video-only, 1 run for audio-only and 6 runs for mixed).
- Criterias:
  - How many queries they find the reference data or correctly tell there is none to find
  - When a copy is detected, how accurately the run locates the reference data in the test data
  - How much time is required for query processing
Measures

- **Minimal Normalized Detection Cost Rate (NDCR):** A cost-weighted combination of the probability of missing a true copy and the false alarm rate.

  \[
  DCR = C_{Miss} \times P_{Miss} \times R_{target} + C_{FA} \times R_{FA} 
  \]

  \[
  NDCR = \frac{DCR}{C_{Miss} \times R_{target}} 
  \]

- **Copy rate** \(R_{target}\): 0.5/hr, **Cost of a miss** \(C_{Miss}\): 10, **Cost of a false alarm** \(C_{FA}\): 1

- **\(P_{Miss}\): Probability of a miss, \(R_{FA}\): False alarm rate**

- **Copy location accuracy:** mean F1 (harmonic mean of Precision (P) and Recall (R): \(F1 = \frac{2 \times P \times R}{P + R}\))

- **Copy detection time:** mean processing time (s)
Top 10 Min. NDCR Performance

T1: Cam Cording
T3: Insertion of patterns
T4: Re-encoding
T5: Change of gamma
T6, T7: Decrease in quality
T8, T9: Post Production
T10: Random combination of 5 transformations

Content-based image and video retrieval
Top 10 F1 Performance

T1: Cam Cording  T3: Insertion of patterns  T5: Change of gamma  T8, T9: Post Production
T2: Pict. In Pict.  T4: Re-encoding  T6, T7: Decrease in quality  T10: Random combination of 5 transformations
### Top 10 sites per transformation (Min. NDCR)

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<th>Site Name</th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>T6</th>
<th>T7</th>
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</table>
INRIA-LEAR’s Video Copy Detection System

Matthijs Douze, Adrien Gaidon, Herve Jegou, Marcin Marszalek, Cordelia Schmid
Large scale object/scene recognition

- Each image described by approximately 2000 descriptors
  - $2 \times 10^9$ descriptors to index!

- Database representation in RAM:
  - Raw size of descriptors: 1 TB, search+memory intractable
State-of-the-art: Bag-of-words [Sivic & Zisserman’03]

“visual words”:
- 1 “word” (index) per local descriptor
- only images ids in inverted file
=> 8 GB fits!
Two Main Contributions

- Hamming Embedding
- Weak Geometry Consistency
Overview of INRIA-LEAR Copyright Detection System

Content-based image and video retrieval
Frame Extraction

- **Uniform subsampling:**
  - A fixed number of frames per time unit is extracted (2.5 frames per second). Used in STRICT and SOFT runs.

- **Stable keyframes:**
  - Only a few representative keyframes per shot is extracted (1 frame every 6 seconds on average).
  - In the preliminary experiments, it is observed that the stable keyframe selection caused an insufficient number of frame matches, therefore for the KEYSADVES run, an *asymmetric sampling strategy* is used:
    - Stable keyframes are extracted on the dataset side.
    - The query frames are extracted using uniform subsampling.
Feature Extraction

Keyframe

Compute local descriptors on regions of interest

② Hessian-Affine detector
③ SIFT descriptor

Set of descriptors

Quantization

\[ x \rightarrow q(x) \]

Hamming Embedding

\[ x \rightarrow b(x) \]

Interest region: quantized scales and angles

Compact descriptors: Bag-of-features-like representation

Content-based image and video retrieval
First Issue with Bag-of-Features Representation

- The intrinsic matching scheme performed by BOF is weak
  - for a “small” visual dictionary: too many false matches
  - for a “large” visual dictionary: many true matches are missed

- No good trade-off between “small” and “large”!
  - either the cells are too big
  - or these cells can’t absorb the descriptor noise
20K visual word: false matches
200K visual word: good matches missed
Hamming Embedding

Representation of a descriptor $x$

- Vector-quantized to $q(x)$ as in standard BOF
- short binary vector $b(x)$ for an additional localization in the cell

Two descriptors $x$ and $y$ match iff

$$q(x) = q(y)$$
$$h(b(x); b(y)) < t$$

where $h(a,b)$ is the Hamming distance, $t$ is a threshold
Hamming Embedding

- **Off-line** (given a quantizer)
  - draw an orthogonal projection matrix \( P \) of size \( d_b \times d \)
  - this defines \( d_b \) random projection directions
  - for each cell and projection direction, compute the median value for a learning set

- **On-line**: compute the binary signature \( b(x) \) of a given descriptor
  - project \( x \) onto the projection directions as \( z(x) = (z_1, \ldots, z_{db}) \)
  - \( b_i(x) = 1 \) if \( z_i(x) \) is above the learned median value, otherwise 0
Hamming Embedding: Example
Compared with 20K dictionary: false matches
Hamming Embedding: Example
Compared with 200K visual word: good matches missed
Second Issue with Bag-of-Features Representation

- Re-ranking based on full geometric verification
  - works very well
  - but performed on a short-list only (typically, 100 images)
  → for very large datasets, the number of distracting images is so high that relevant images are not even short-listed!
Weak Geometry Consistency

- Weak geometric information used for all images (not only the short-list)
- Each invariant interest region detection has a scale and rotation angle associated, here characteristic scale and dominant gradient orientation

Scale change 2
Rotation angle ca. 20 degrees

Each matching pair results in a scale and angle difference

For the global image scale and rotation changes are roughly consistent
WGC: Orientation consistency

Max = rotation angle between images
WGC: Scale consistency
Weak Geometry Consistency

- Integrate the geometric verification into the BOF representation
- Only matches that do agree with the main difference of orientation and scale will be taken into account in the final score
- Re-ranking using full geometric transformation still adds information in a final stage
Experimental results

- Evaluation for the INRIA holidays dataset, 1491 images
  - 500 query images + 991 annotated true positives
  - Most images are holiday photos of friends and family
- 1 million distractor images from Flickr
- Dataset size 1,001,491 images
- Vocabulary construction on a different Flickr set
- Almost real-time search speed,
- Evaluation metric: mean average precision (in [0,1], bigger = better)
  - Average over precision/recall curve
Holiday dataset – example queries
Dataset: Venice Channel

Query

Base 1

Base 2

Base 3

Base 4
Dataset: San Marco square
Example distractors - Flickr
Comparison with state-of-the-art

- Evaluation on the holidays dataset, 500 query images, 1 million distracter images
- Metric: mean average precision

<table>
<thead>
<tr>
<th>Database Size</th>
<th>Average Query Time</th>
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<tbody>
<tr>
<td>1000</td>
<td>880 ms</td>
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<tr>
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<tr>
<td>100000000</td>
<td>650 ms</td>
</tr>
</tbody>
</table>
Results – Venice Channel
Results – San Marco

Query

Base 01

Base 02

Base 03

Base 06

Flickr

Flickr
References

- D. Lowe. Distinctive image features from scale-invariant keypoints. IJCV, 60(2):91-110, 2004

- TRECVID. http://trecvid.nist.gov