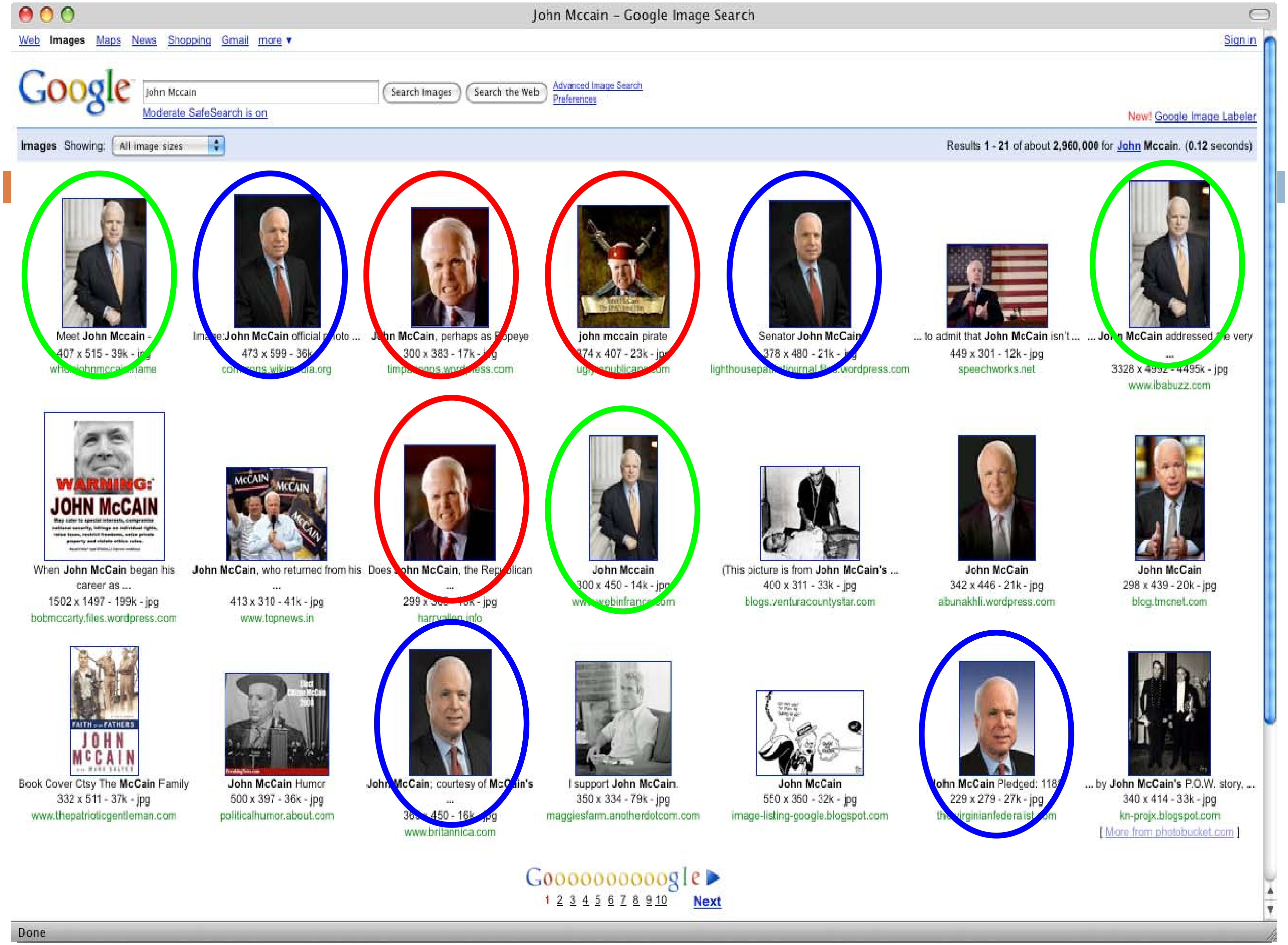
NEAR-DUPLICATE KEYFRAME RETRIEVAL BY NONRIGID IMAGE MATCHING

Jianke Zhu, CUHK
Steven C.H. Hoi, NTU
Michael R. Lyu, CUHK
Shuicheng Yan, NUS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Meet John Mccain -
407 x 515 - 39k - jpg
Senator John McCain
378 x 480 - 21k - jpg
... to admit that John McCain isn't ...
449 x 301 - 12k - jpg
speechworks.net
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When John McCain began his career as ...
1502 x 1497 - 199k - jpg
bobmccarty.files.wordpress.com
John McCain, who returned from his ...
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John Mccain
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blogs.venturacountystar.com
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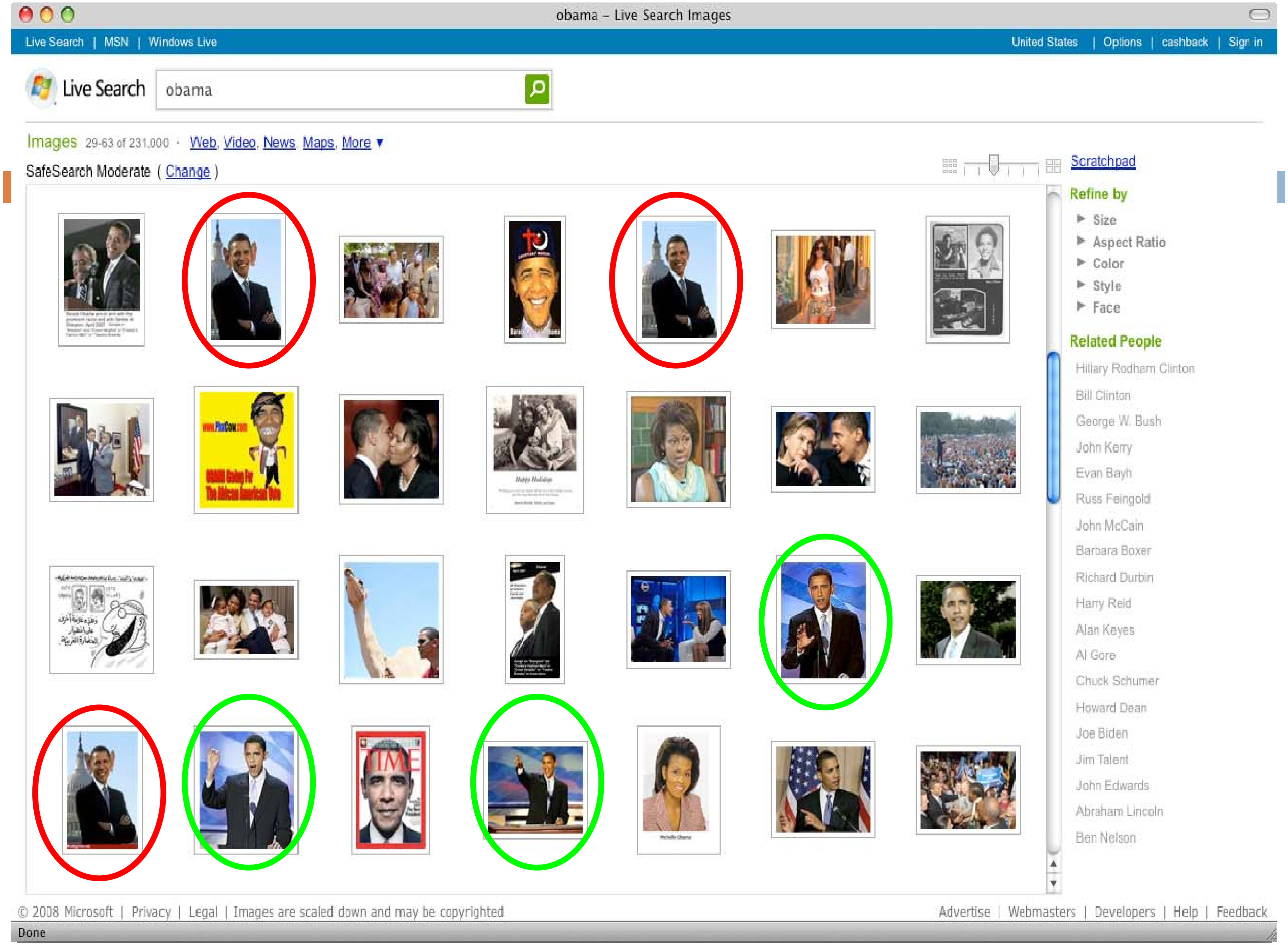
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Hillary Rodham Clinton
Bill Clinton
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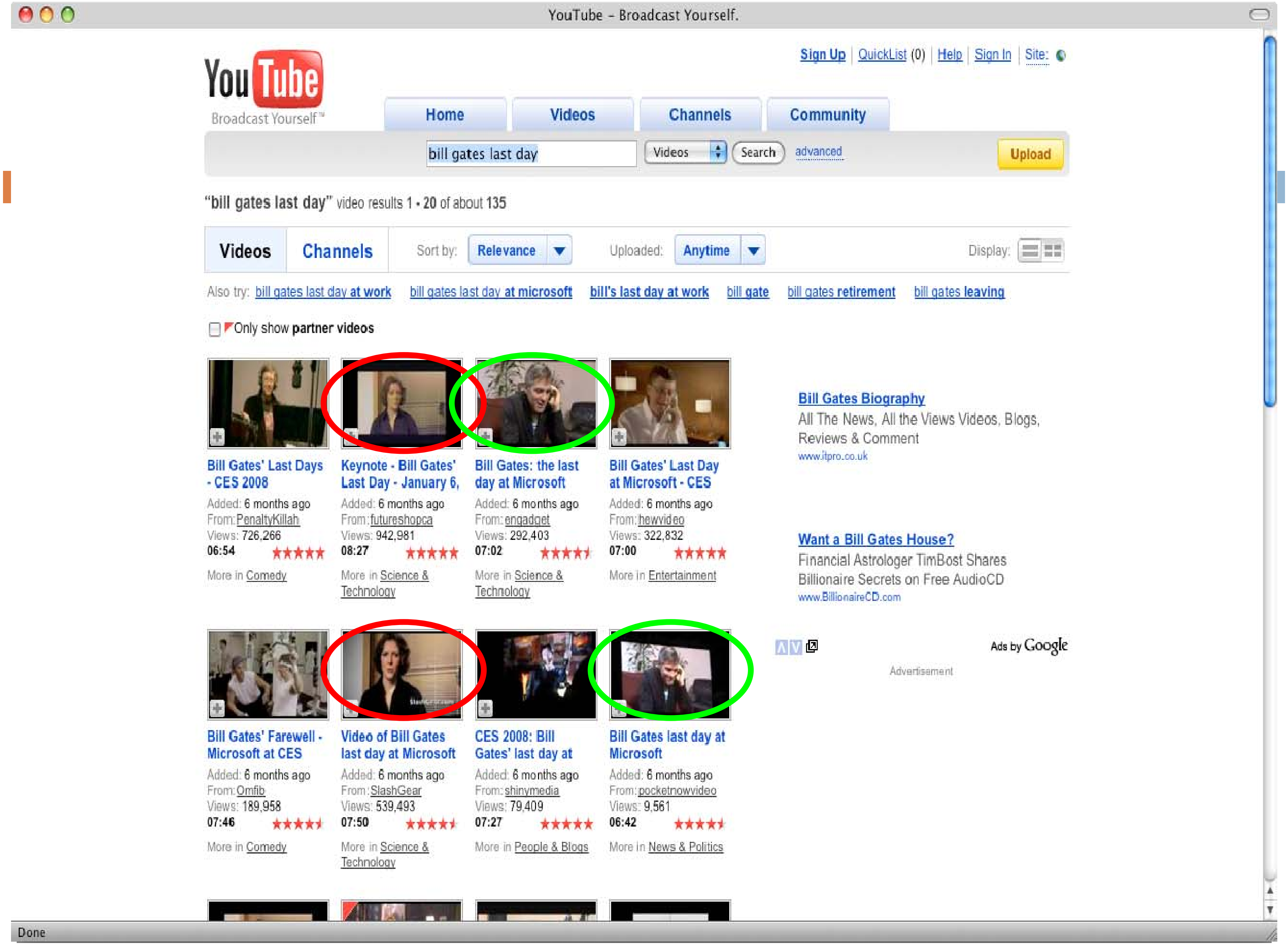
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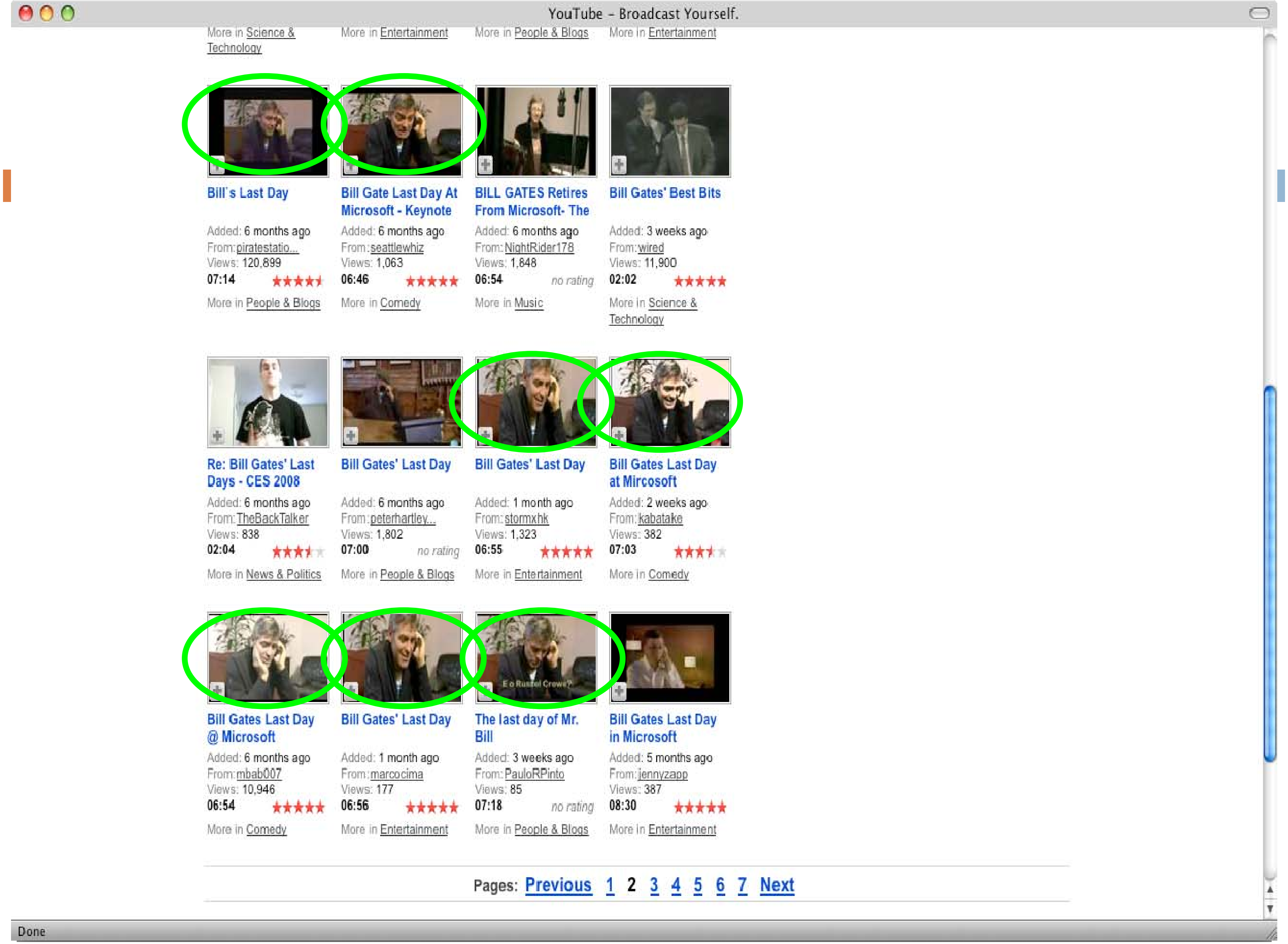
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Bill Gates Last Day in Microsoft
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Near-Duplicate Keyframes

- Problem
  - Duplicate video search
  - Copyright detection.

- Challenges
  - Different capture devices under a variety of illumination conditions.
  - Video editing: photometric and geometric transformations, and occludes original video by adding captions.

Outline

- Related work
- Nonrigid Image Matching
  - Formulation
  - Algorithm
  - Case Studies
- Multi-level Near-Duplicate Keyframe (NDK) Retrieval
  - Framework
  - Formulation as a Machine Learning Task
  - Semi-supervised Support Vector Machine
- Experiements
- Conclusion

Related work I: Appearance-based Methods

- Extend content-based image retrieval techniques for NDK detection and retrieval

- Measure the similarity between two keyframes based on the extracted global features:
  - Color histogram and color moment (Zhang and Chang ACM MM'04, A. Qamra et al. TPAMI'05).
  - Grid color moment (Zhao et al. CIVR'06)

- Very efficient for finding identical copies

- Not very robust to the variations of illumination changes, geometric transformations and occlusions.

Related work II: Feature-based Methods

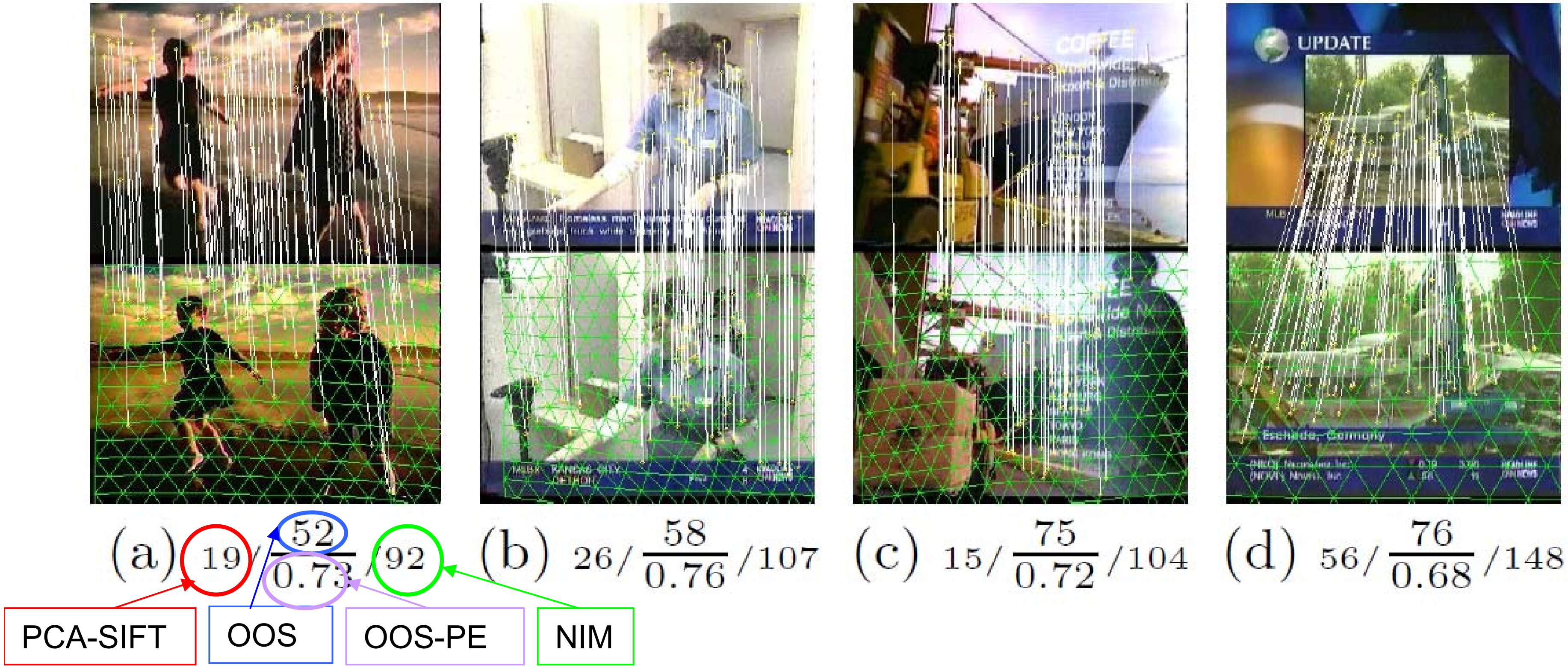
- Detect local keypoints in two keyframes
- Measure the similarity by counting the number of correct correspondences between two keypoint sets
- Overcome the limitations of global appearance based methods
- Incur a heavy computational cost for point matching

Related work II: Feature-based Methods

- PCA-SIFT with LSH indexing (Ke et al. ACM MM'04)
  - Efficient feature matching with a rigid projective geometry assumption
- Attributed Relational Graph (ARG) (Zhang and Chang, ACM MM'04)
  - Involves the process of stochastic belief propagation
- One-to-One Symmetric matching (OOS) (Zhao et al. TMM'07)
  - Bipartite graph matching
  - A local smoothing constraint to remove the outlier matches
- OOS with Pattern Entropy (PE) (C-W. Ngo et al. ACM MM'06)
- Visual Keywords (VK) (Wu et al. CIVR'07)

Nonrigid Image Matching (NIM)

- Nonrigid transformation between the two NDKs
- Progressive Finite Newton approach (CVPR'07, TPAMI'08)
  - A closed-form solution for nonrigid image matching



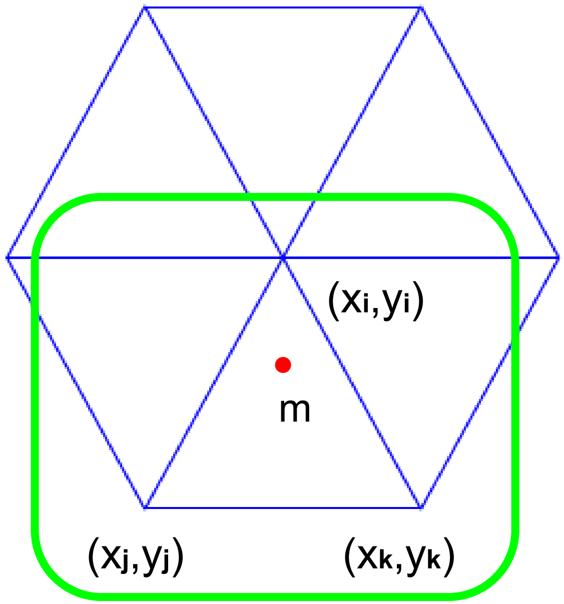
Nonrigid Image Matching

- Estimate the explicit mesh model with a few deformation parameters
- Recover the local deformations from salient feature correspondences between two images and reject the outlier matches simultaneously
- Choose the total number of inlier matches as a confidence measure to judge wheather the two keyframes are near-duplicate or not.

2D Nonrigid Shape Model

$$\mathbf{s} = \begin{bmatrix} \mathbf{x} & \mathbf{y} \end{bmatrix}^\top = \begin{bmatrix} x_1 & x_2 & \dots & x_N & y_1 & y_2 & \dots & y_N \end{bmatrix}^\top$$

$$T_{\mathbf{s}}(\mathbf{m}) = \begin{bmatrix} x_i & x_j & x_k \\ y_i & y_j & y_k \end{bmatrix} \begin{bmatrix} \xi_1 & \xi_2 & \xi_3 \end{bmatrix}^\top$$



where (ξ_1, ξ_2, ξ_3) are the barycentric coordinates for the point m.

Nonrigid Image Matching

Energy function:

$$E(\mathbf{s}) = E_c(\mathbf{s}) + \lambda_r E_r(\mathbf{s})$$

Error term

Regularization term

- Ec(s) is the sum of the weighted square residual errors for the matched points.

$$E_c(\mathbf{s}) = \sum_{\mathbf{m} \in \mathcal{M}} \omega_{\mathbf{m}} \mathcal{V}(\delta, \sigma)$$

Robust Estimator

- *Er*(s) represents the surface deformation energy, is composed of the sum of the squared second-order derivatives of the mesh vertex coordinates

$$E_r(\mathbf{s}) = \mathbf{s}^\top \begin{bmatrix} K & 0 \\ 0 & K \end{bmatrix} \mathbf{s}$$

where K is a sparse and banded matrix which is determined by the structure of the mesh model

- λ_r is a regularization coefficient.

Finite Newton Formulation

- Modified Finite Newton optimization scheme
- Update equation: $\mathbf{s} \leftarrow \mathbf{s} - \gamma H^{-1} \nabla$
- Set step size r = 1, and obtain the linear equation:

$$\begin{bmatrix} \lambda_r K + A & 0 \\ 0 & \lambda_r K + A \end{bmatrix} \mathbf{s} = \begin{bmatrix} \mathbf{b}_x \\ \mathbf{b}_y \end{bmatrix} \qquad A = \sum_{\mathbf{m} \in M_1} \frac{\omega_{\mathbf{m}}}{\sigma^n} \mathbf{t}\mathbf{t}^\top$$

$$\mathrm{b} = \begin{bmatrix} \mathrm{b}_x \\ \mathrm{b}_y \end{bmatrix} = \sum_{\mathbf{m} \in M_1} \frac{\omega_{\mathbf{m}}}{\sigma^n} \begin{bmatrix} u\mathbf{t} \\ v\mathbf{t} \end{bmatrix} \qquad \mathbf{t}_i = \xi_1 \quad \mathbf{t}_j = \xi_2 \quad \mathbf{t}_k = \xi_3$$

$$\mathbf{x} = (\lambda_r K + A)^{-1} \mathbf{b}_x$$

$$\mathbf{y} = (\lambda_r K + A)^{-1} \mathbf{b}_y$$

Progressive Finite Newton Algorithm

- **Given:** mesh model $\mathbf{s}_0$, ν, λ_r, σ_0
- **Pre-compute:** K and (ξ_1, ξ_2, ξ_3) for each keypoint $\mathbf{m}_0$
- **Detection:** for a given image

  Obtain M by feature matching
  Select active set by modified RANSAC
  While $\sigma > 2$
    Compute A and $\mathbf{b}$
    Solve linear system
    Calculate residual error δ and inlier set M_1
    $\sigma = \nu \cdot \sigma$

$$\mathbf{x} = (\lambda_r K + A)^{-1} \mathbf{b}_x$$

$$\mathbf{y} = (\lambda_r K + A)^{-1} \mathbf{b}_y$$

- **Output:** mesh vertices $\mathbf{s}$

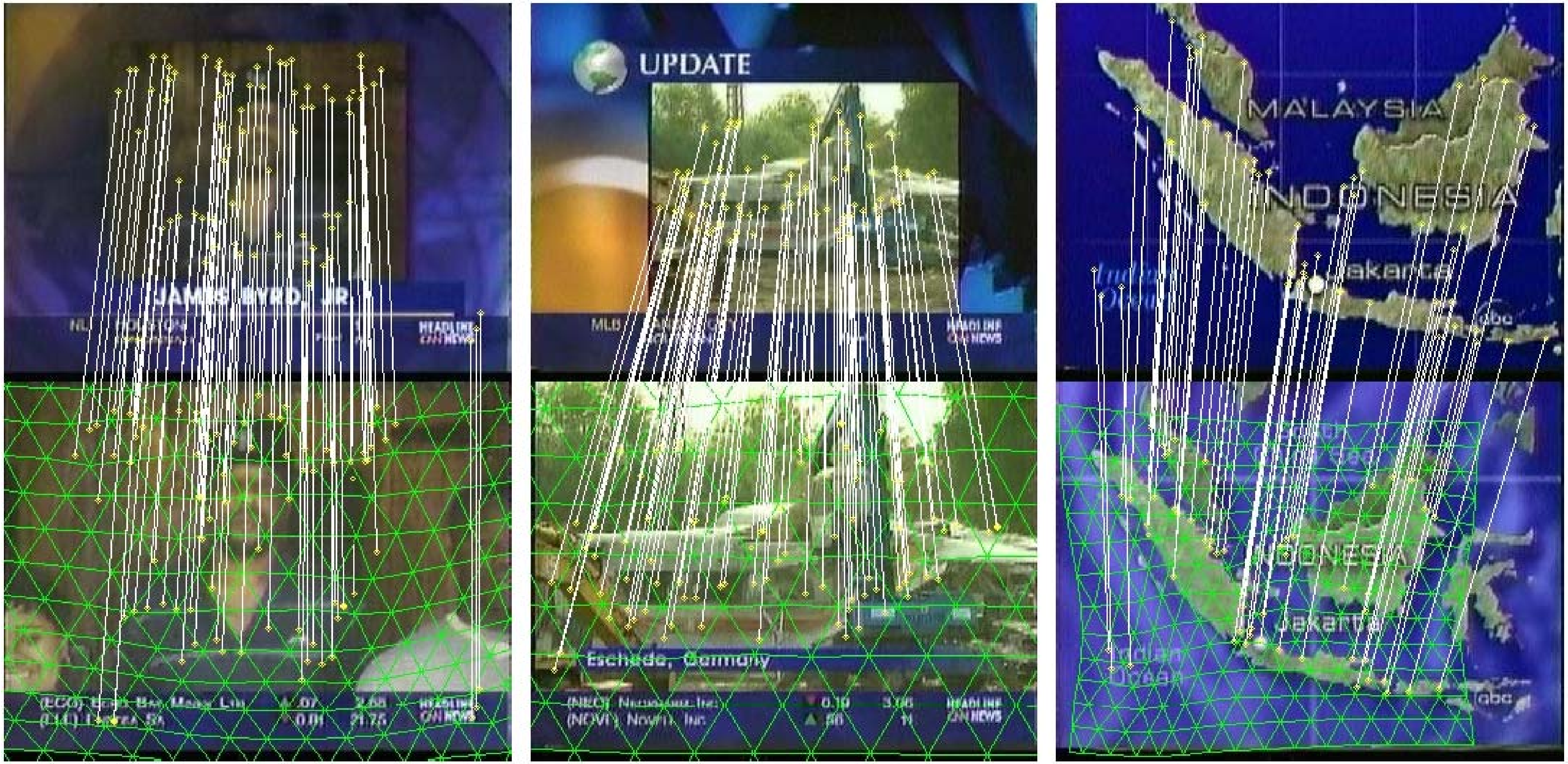
Case Study: Viewpoint Changes

(a) Viewpoint changes

Case Study: Object Movements

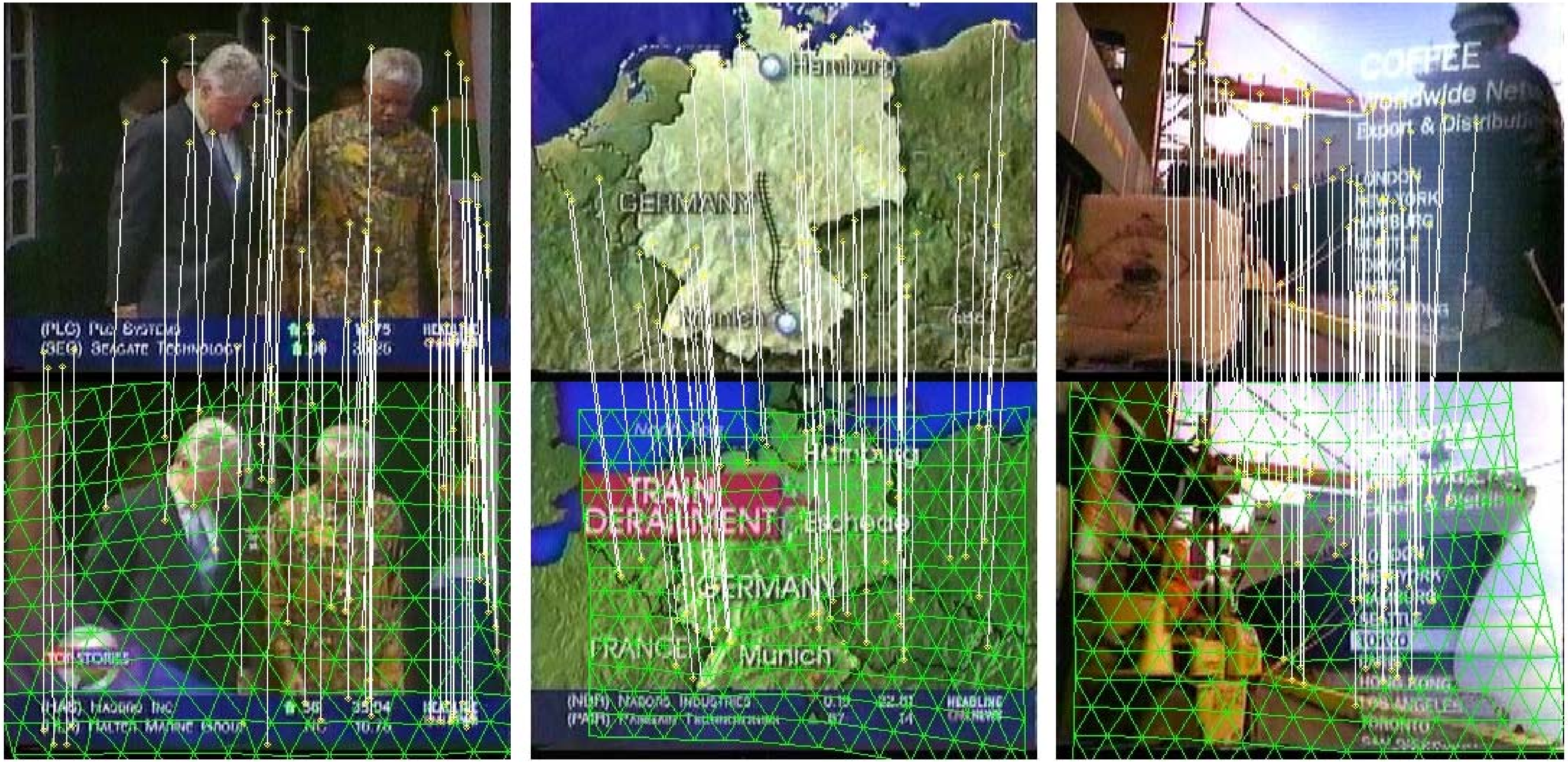
(b) Object movements

Case Study: Subimage



(d) Subimage duplicates

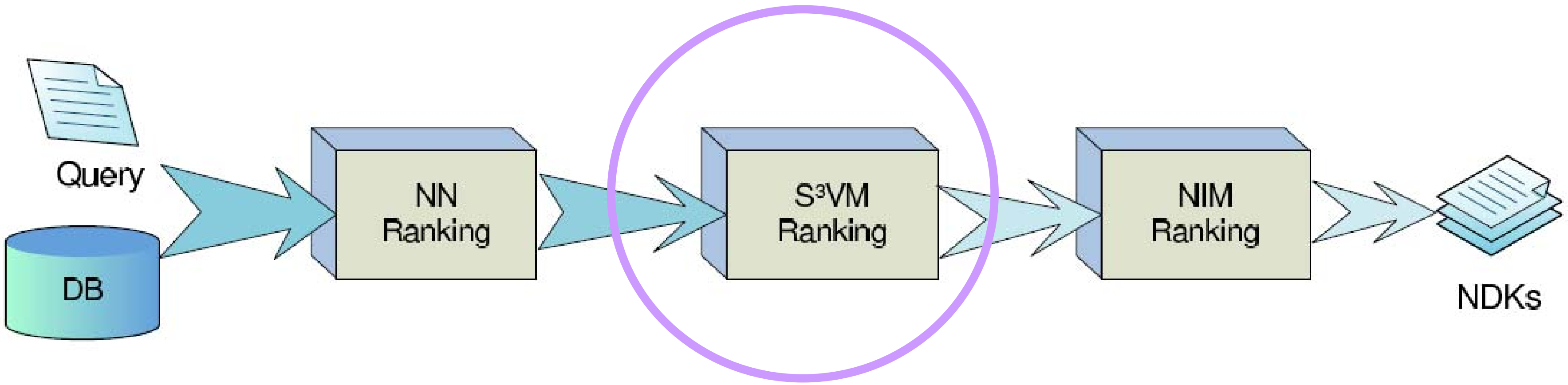
Case Study: Occlusions



(f) Partial occlusions

Multi-level NDK Retrieval

- Local feature matching in NIM is computational intensive
- To improve the efficiency and scalability:



Formulation as a Machine Learning Task

- Query set of label image examples ($\mathbf{x}_i \in R^d$)

  $$Q = \{(\mathbf{x}_1, +1), \ldots, (\mathbf{x}_l, +1)\}$$

- Gallery set of unlabeled image examples

  $$\mathcal{G} = \{\mathbf{x}_{l+1}, \ldots, \mathbf{x}_{l+u}\}$$

- Difficulties
  - No negative samples available
  - Small sample learning: very few labeled examples
- Solution
  - Pseudo-negative example (Rong et al. ACM MM'03).
  - Semi-Supervised Learning

Semi-Supervised SVM

- SVM
  - Learn an optimal hyperplane with maximal margin
  - SVM in a regularization framework

$$\min_{f \in \mathcal{H}_K} \frac{1}{l} \sum_{i=1}^{l} \max(0, 1 - y_i f(\mathbf{x}_i)) + \lambda \|f\|_{\mathcal{H}_K}^2$$

$$f(\mathbf{x}) = \sum_{i=1}^{l} \alpha_i k(\mathbf{x}, \mathbf{x}_i)$$

- Semi-Supervised SVM
  - Utilize the unlabeled data
  - **Unified kernel learning: data-dependent Kernel**

Learning a Data-dependent Kernel

- Kernel deformation (Vikas et al. ICML'05)

  First estimate the geometry of the underlying marginal distribution

  Derive a data dependent kernel by incorporating the estimated geometry

- Assume $< f, g >_{\tilde{\mathcal{H}}} = < f, g >_{\mathcal{H}} + \mathbf{f}^\top M \mathbf{g}$
- New kernel function $\tilde{k}(\mathbf{x}, \mathbf{y}) = k(\mathbf{x}, \mathbf{y}) + \kappa_{\mathbf{y}}^\top \mathbf{d}(\mathbf{x})$

  where $\mathbf{d}(\mathbf{x}) = -(I + MK)^{-1} M \kappa_{\mathbf{x}}$

$$M = L^p \quad L = D - Q \qquad D_{ii} = \textstyle\sum_i Q_{ij}$$

$$Q_{ij} = Q_{ji} = \begin{cases} e^{-\frac{\|\mathbf{x}_i - \mathbf{x}_j\|^2}{2\sigma^2}}, & \mathbf{x}_i \text{ and } \mathbf{x}_j \text{ are adjacent} \\ 0, & \text{otherwise,} \end{cases}$$

- New kernel function

$$\tilde{k}(\mathbf{x}, \mathbf{y}) = k(\mathbf{x}, \mathbf{y}) - \kappa_{\mathbf{y}}^\top (I + MK)^{-1} M \kappa_{\mathbf{x}}$$

$$\kappa_{\mathbf{y}} = (k(\mathbf{x}_1, y), \ldots, k(\mathbf{x}_n, y))^\top$$

Overview of Experiments

- Experimental testbeds
- Feature extraction
- Experiment I: ranking on global feature
- Experiment II: re-ranking with NIM on local features
- Computational cost

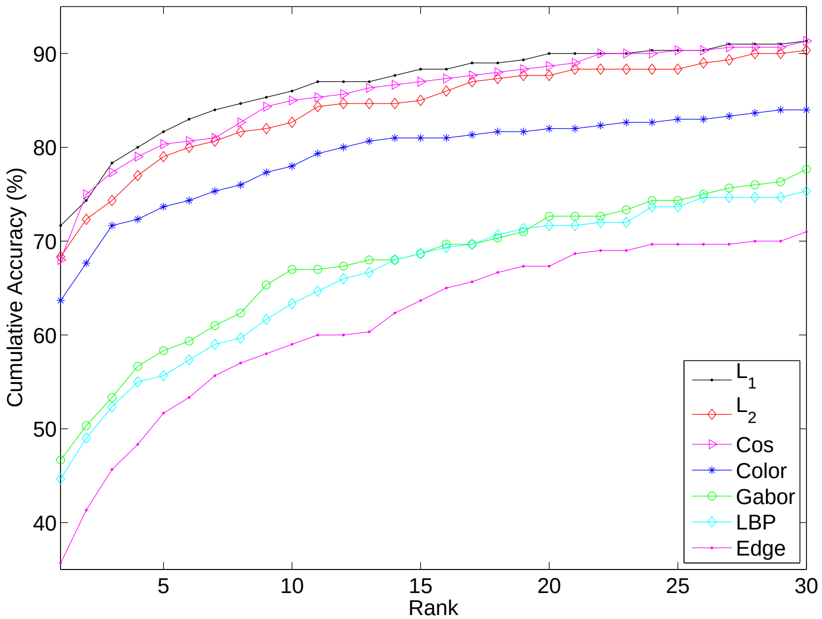
Experimental testbeds

- Columbia's TRECVID2003 dataset
  - 600 keyframes size of 352x264
  - 150 near-duplicate image pairs
  - 300 non-duplicate images
- CityU's TRECVID 2004 dataset
  - 7006 keyframes
  - 3388 near-duplicate image pairs involve a total of 1953 keyframes
  - One keyframe may be associated with several near-duplicate pairs
- Evaluation protocols
  - Each query contain single query image, remaining keyframes are regarded as the gallery set
  - Average cumulative accuracy metric

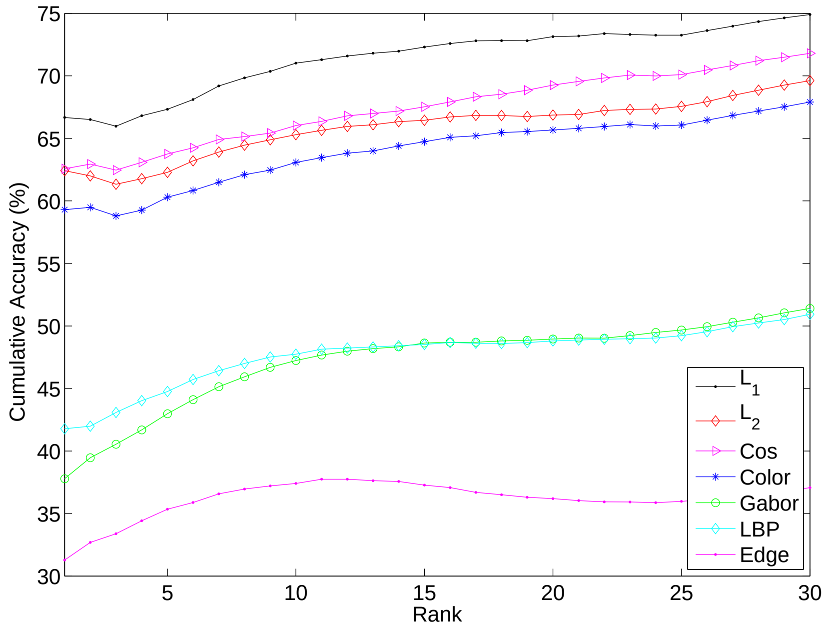
Feature Extraction

- Global Feature: 297-dimensional vector
  - Grid Color moment:
    - 3x3 grid, color mean, variance, skewness for R, G, B
  - Local Binary Pattern (LBP)
    - 59-dimensional LBP histogram
  - Gabor wavelets texture
    - 5 scales and 8 orientations, 3 moments for each subimage
  - Edge
    - Ege orientation histogram, Canny edge detector
- Local Feature Extraction
  - SIFT, PCA-SIFT v.s. SURF (H. Bay et al. ECCV'06)
  - SURF is used for NIM matching:
    - takes advantage of fast feature extraction using integral images
    - more compact than SIFT

Ranking on Global Feature: Similarity and Features



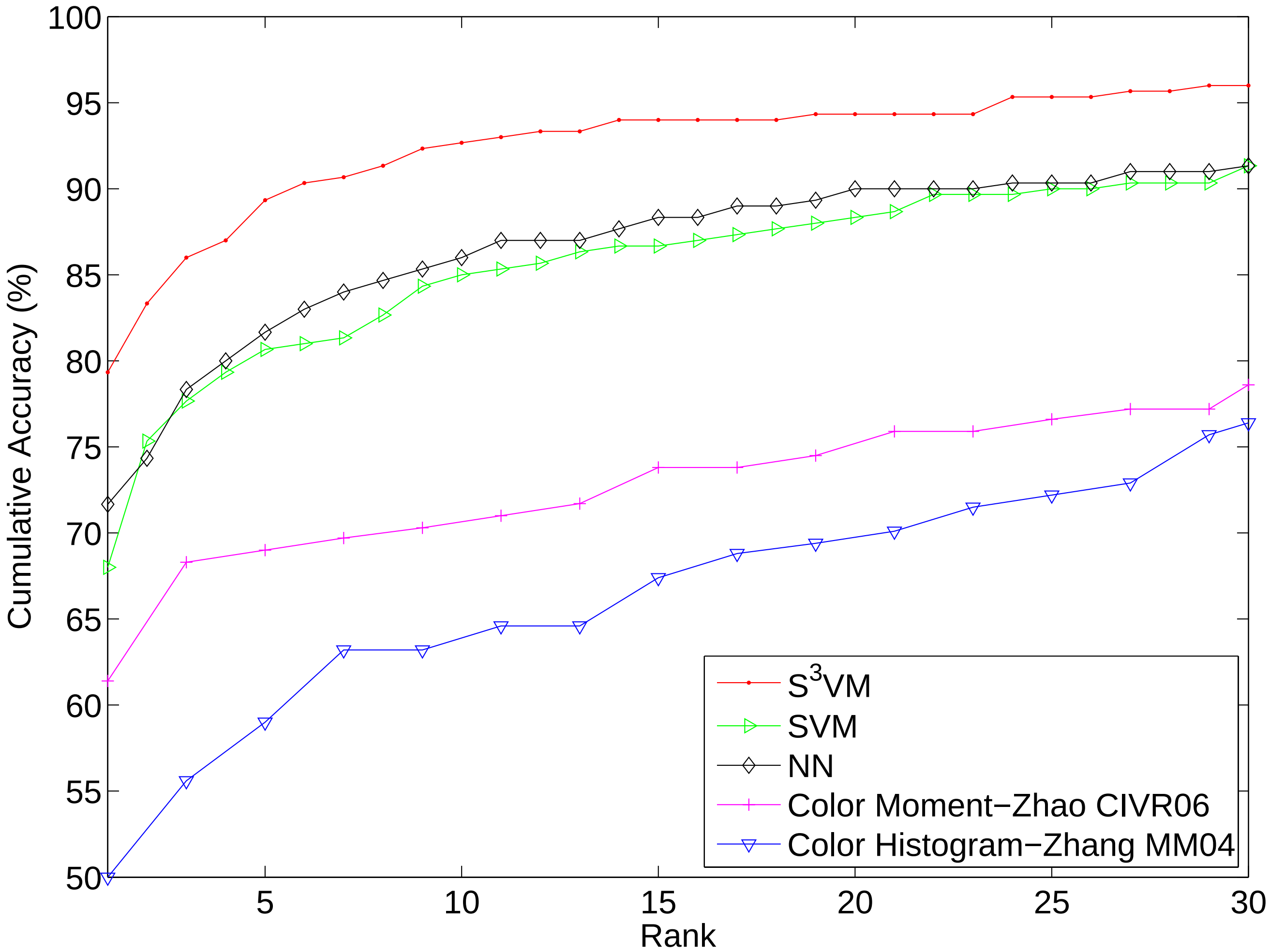
TRECVID2003 dataset



TRECVID2004 dataset

- **L_1>Cos>L_2**
- **Color Moments>Gabor, LBP>Edge**

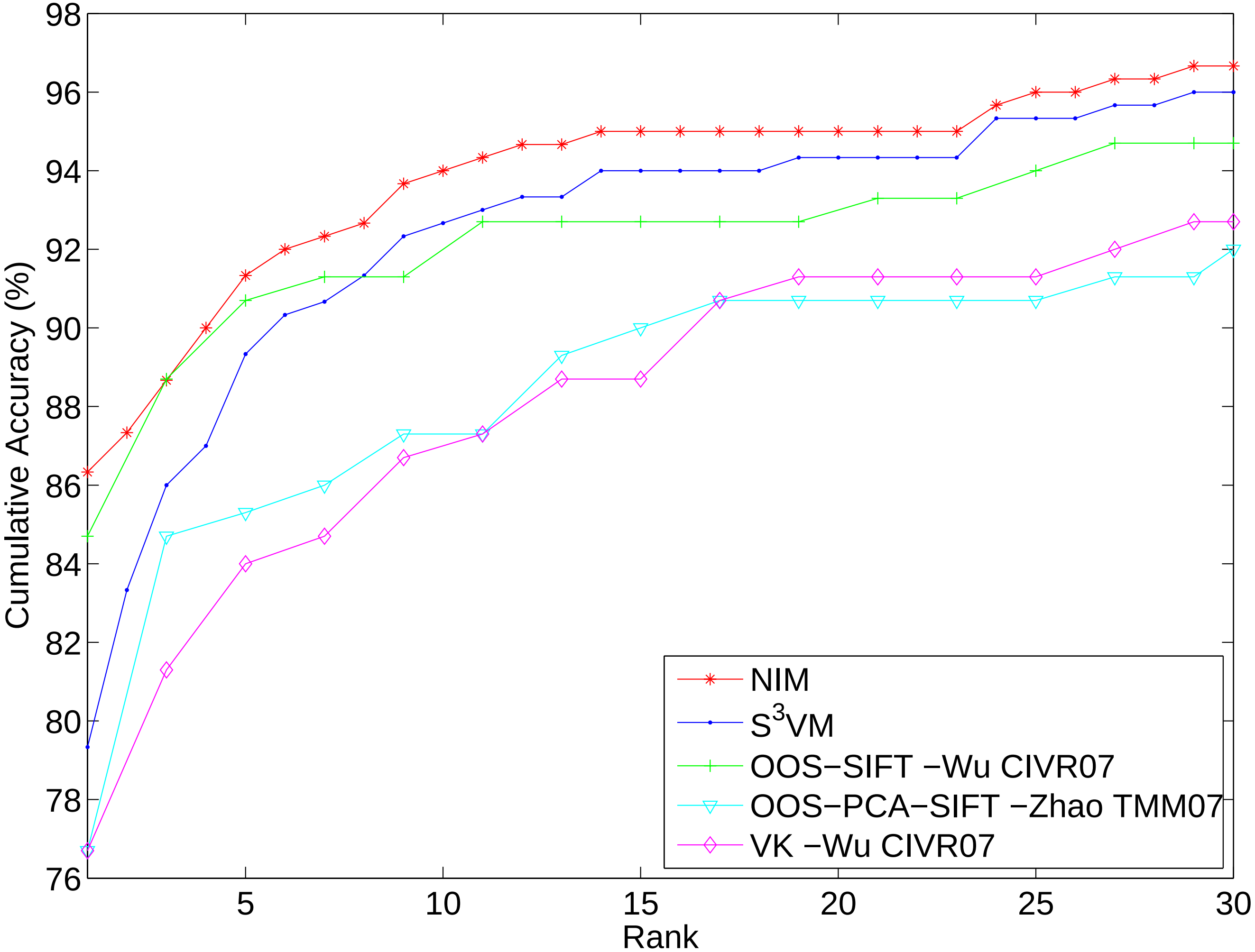
Ranking on Global Feature



TRECVID2003 dataset

S3VM>NN, SVM

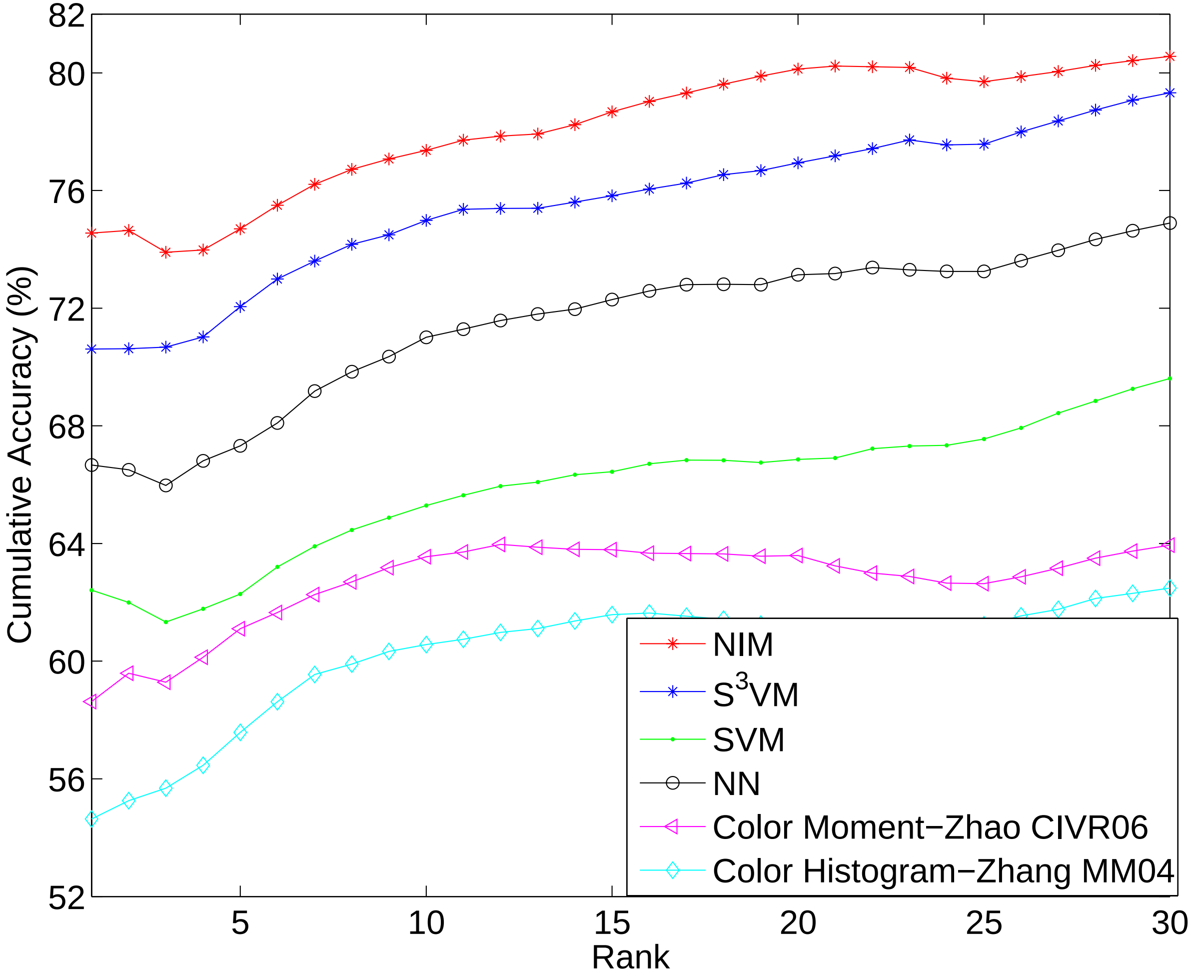
Re-ranking with NIM on Local Features



TRECVID2003 dataset

NIM>OOS>S3VM

Re-ranking with NIM on Local Features



TRECVID2004 dataset

NIM>S3VM>NN>SVM

Computational Cost Comparison

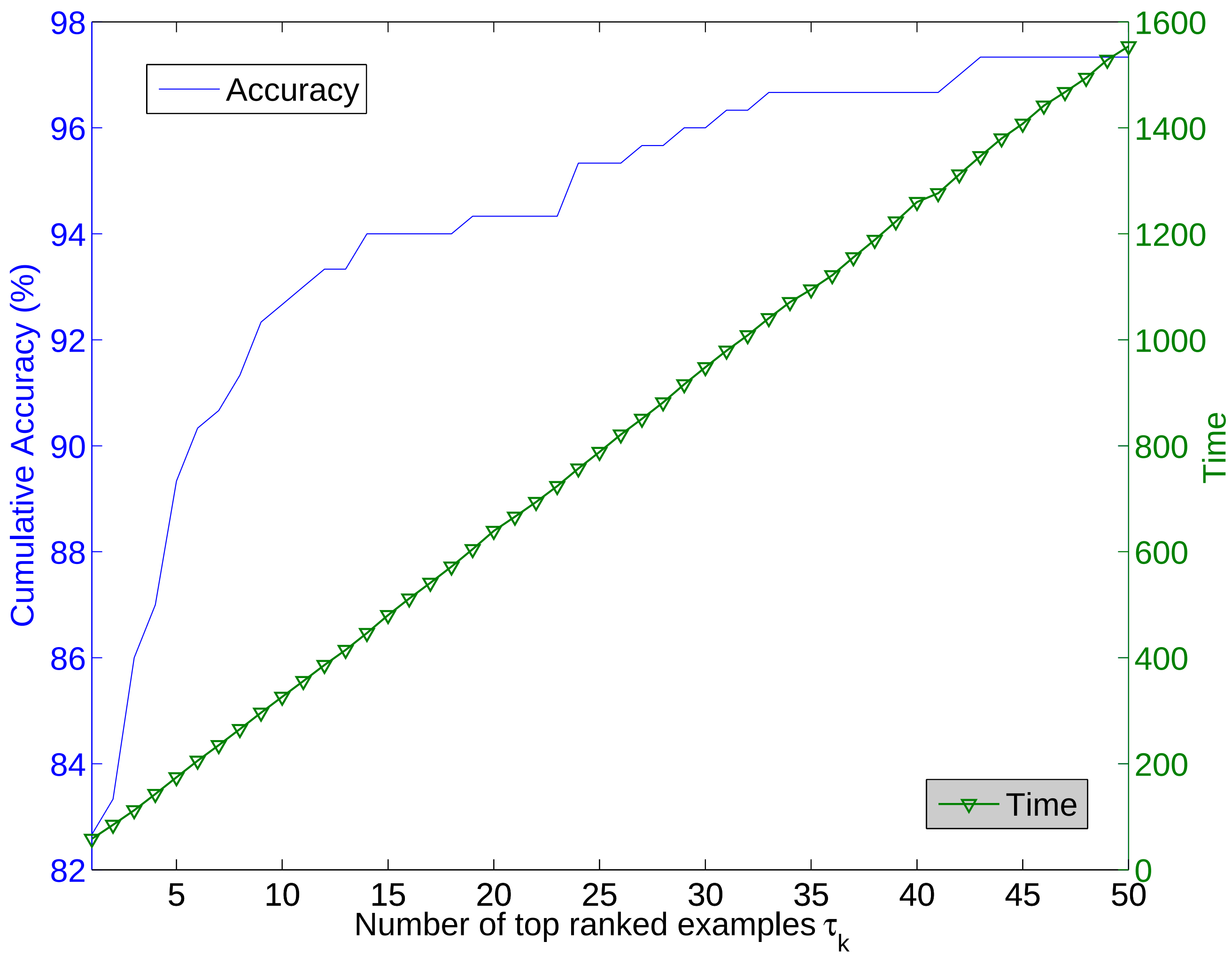
Table 1: Comparison of overall time cost of 300 queries on the TRECVID2003 dataset.

NIM	S^3VM	NN	OOS [24]	VK [24]
15.8min	3sec	1sec	6.5hour	1.5min

Table 2: Comparison of overall time cost of 1,953 queries on the TRECVID2004 dataset.

NIM	S^3VM	NN	OOS [24]	VK [24]
103.5min	8.1min	30sec	N/A	N/A

Efficiency and performance on TRECVID 2003



Conclusion

- A novel nonrigid image matching method for NDK retrieval.
- In contrast to the traditional approaches,
  - Recover the explicit nonrigid mapping between two NDK.
  - A robust coarse-to-fine optimization scheme
  - Not only detect the NDK pairs, but also recover the local deformations between them simultaneously
  - An effective multi-level ranking scheme
  - A semi-supervised ranking technique to improve the ranking performance with the unlabeled data
- Extensive experimental evaluations on two testbeds extracted from TRECVID corpora.
- More effective than conventional approaches

Q/A