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WALRUS: A Similarity Retrieval Algorithm for Image Databases

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Outline

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- Problem Formulation
- Motivation
- Related work
- Our Contributions
  - Similarity Model
  - WALRUS Similarity Retrieval Algorithm
- Experimental Studies

Motivation

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- Hundreds of thousands of digital images are available
  - Internet
  - Medical Images
  - Satellite images
  - TV production
  - Multimedia
- Content-based querying of images
  - Medical diagnosis
  - Weather predication
  - Web search engine for images
  - E-commerce

Problem Formulation

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- Given:
  - A set of images
- Find:
  - All images similar to a given image
  - All pairs of similar images

Traditional Approaches

Basic Idea

- Extract a feature signature for each image
- Map signatures to k-dimensional points
- Use a multi-dimensional disk-based index to store and search these points
  - dimensionality curse: Spatial Indices do not work well for high dimensional data
- Given a query image, the index is used to locate signatures close to the query point

Traditional Signatures

- Color Histogram
  - Characterize the color composition of an image, regardless of its scale or orientation
  - Do not contain any any shape, location or texture information
  - Two images with similar color composition may in fact very different shapes

Traditional Signatures

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- Separate distance functions for color, shape and texture and combine them
- Wavelet coefficients
  – wavelets capture shape, texture and location information in a single unified framework

Related Work

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- QBIC[Nib93, FSN95], [JFS95], WBIIS[WWWFS98]
  - Generates a single signature per image
  - Fails when the images contain similar objects, but at different locations or varying sizes
- [Smi97]
  - Divide an image into individual objects
  - Manual extraction can be very tedious and time consuming
  - Inaccurate in identifying objects and not robust

QBIC

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- Features: color space, shapes, texture
  - Color features: color histogram with 64 colors
    - Distance of two histograms $\vec{x}$ and $\vec{q}$: cross talk
    - $d_{hist}(\vec{x}, \vec{q}) = (\vec{x} - \vec{q}) A (\vec{x} - \vec{q})^t$
    - None of the spatial access methods can handle crosstalk
    - Use $d_{RGB}(\vec{x}', \vec{y}')$ that is Euclidean distance
      where $\vec{x}' = (\sum r_i, \sum g_i, \sum b_i)$
    - Note that d_{RGB} is a lower bound of d_{hist}:

      =>Allows the use of spatial access methods

      =>No false dismissals

WBIIS

- Features
  - Daubechies' wavelets for color space
- Two-step approach
  - First filter based on the variance
  - Refine the search by a feature vector match
- Two-level multi-resolution matching may be used
- Different weighting of the color components: correct estimation of weights is very hard
- Fails to detect similar images where similar objects are placed at different locations or in varying sizes

WBIIS

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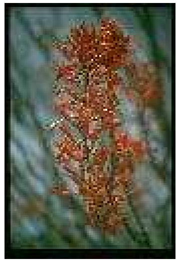
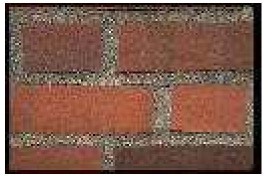
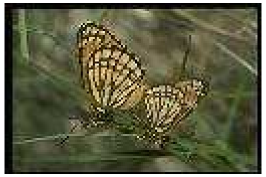
Query image










WALRUS (Similarity Model)

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- Automatically extract regions from an image based on the complexity of images
- A single signature is used per each region
- Two images are considered to be similar if they have enough similar region pairs

Similar Images

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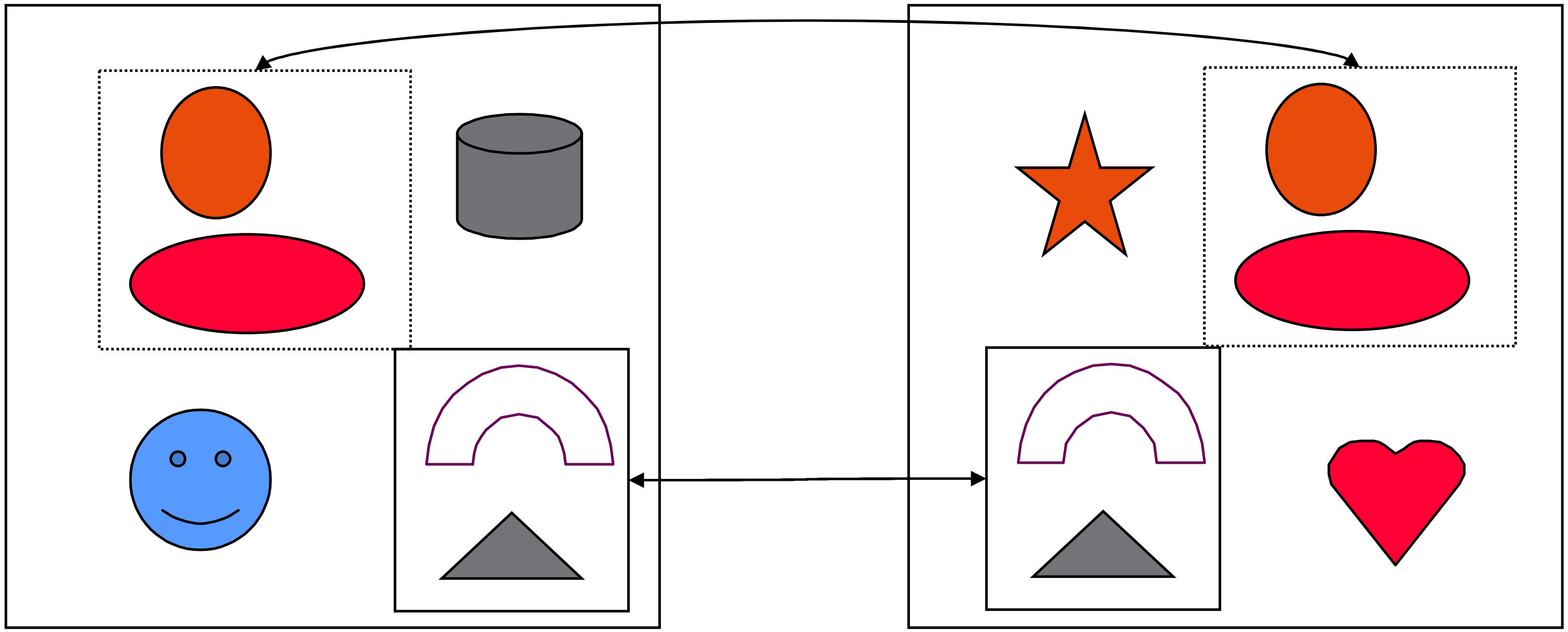
Our Similarity Model



WALRUS (Overview)

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- Break each image with sliding windows
- Generate signatures for sliding windows
- Cluster the sliding windows
  - Automatically extract regions from an image based on the complexity of images
  - A single signature is used per each region (e.g. centroid)
- Store the representatives of clusters into disk-based spatial index
- Region Matching
- Image Matching

Wavelets (1-D Harr Wavelets)

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Resolution	Average	Detail Coefficients
2	[2, 2, 5, 7]	
1	[2, 6]	[0, 1]
0	[4]	[2]

Wavelet coefficient: [4, 2, 0, 1]

Wavelets (2-D Harr Wavelets)

- Standard decomposition
  - Apply 1-D wavelet transformation to each row
  - Apply 1-D wavelet transformation to each column
- Non-standard decomposition
  - apply one step of 1-D wavelet transformation to each row and column repeatedly

Example (2-D Harr Wavelet)

1.0	2.0	1.0	2.0
3.0	4.0	3.0	4.0
1.0	2.0	1.0	2.0
3.0	4.0	3.0	4.0

→

2.5	0.5	2.5	0.5
1.0	0.0	1.0	0.5
2.5	0.5	2.5	0.5
1.0	0.0	1.0	0.5

1.0	2.0
3.0	4.0

→

1.5	0.5
3.5	0.5

→

2.5	0.5
1.0	0.0

Example (2-D Harr Wavelet)

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2.5	0.5	2.5	0.5
1.0	0.0	1.0	0.5
2.5	0.5	2.5	0.5
1.0	0.0	1.0	0.5

→

2.5	2.5	0.5	0.5
2.5	2.5	0.5	0.5
1.0	1.0	0.0	0.0
1.0	1.0	0.0	0.0

WALRUS (Step 1)

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- Generation of Signatures for Sliding Windows
  - Each image is broken into sliding windows.
  - For the signature of each sliding window, use s^2 coefficients from lowest frequency band of the Harr wavelet.
  - Naive Algorithm: $O(N\omega_{\max}^2)$
  - Dynamic Programming Algorithm: $O(NS\log_2\omega_{\max})$

N - number of pixels in the image

S - s^2

$\omega_{\max}$ - max window size

$$s << \omega_{\max}$$

WALRUS (Step 2)

- Clustering Sliding Windows
  - Cluster the windows in the image.
    Use pre-clustering phase of BIRCH
  - Each cluster defines a region in the image.
  - For each cluster, the centroid is used as a signature. (c.f. bounding box)

WALRUS (Step 3)

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- Region Matching
  - Each region of the images is stored in R*-tree.
  - For each region of the query image, find all regions in the database that are similar.

    (i.e. Retrieve regions whose signatures are within

    ε distance.)

WALRUS (Step 4)

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- Image Matching
  – From all matching pairs for query image Q and each target image T, compute the best similar region pair set for Q and T.

    (i.e. Find the one that covers the maximum area in
    two images.)

WALRUS

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Query image

WBIIS

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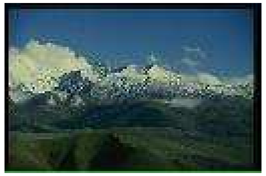
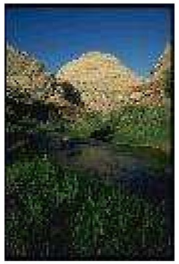
Query image

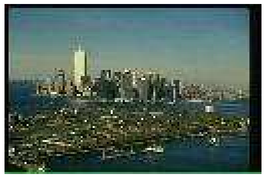
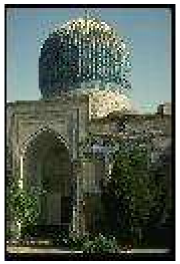
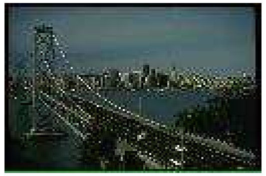









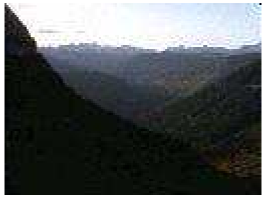


WALRUS

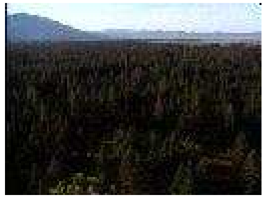
Query image





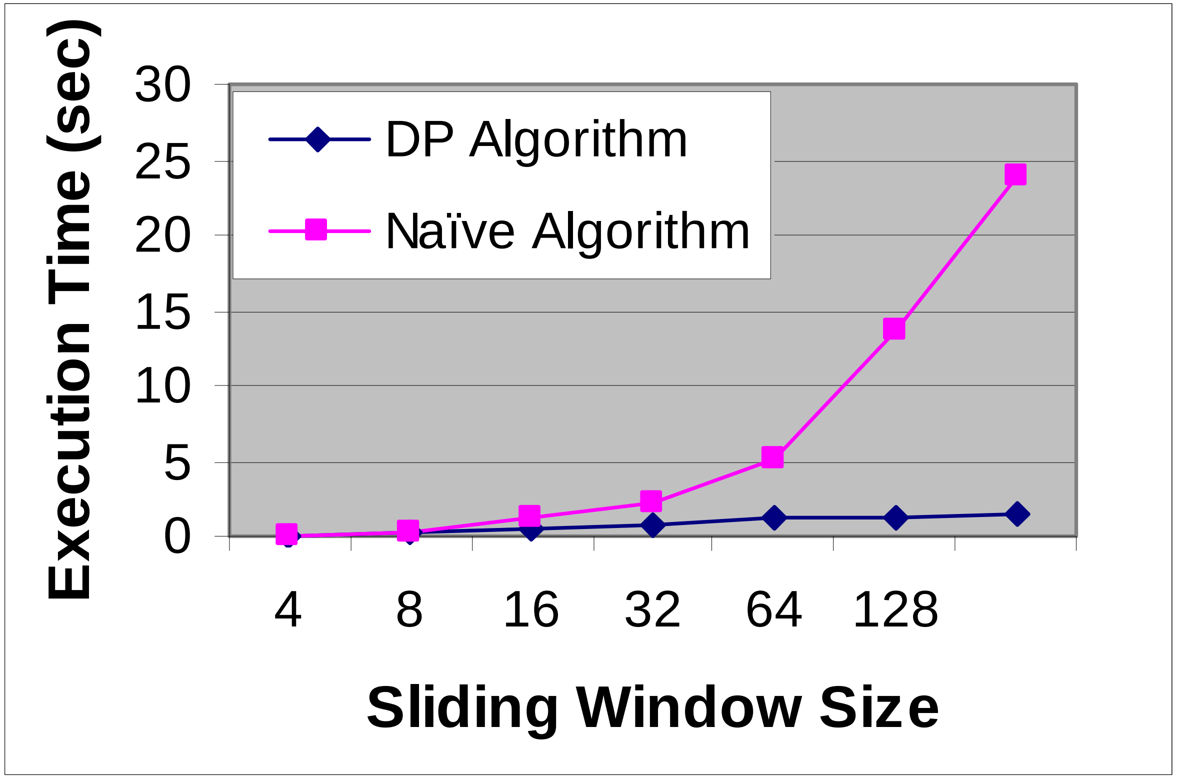






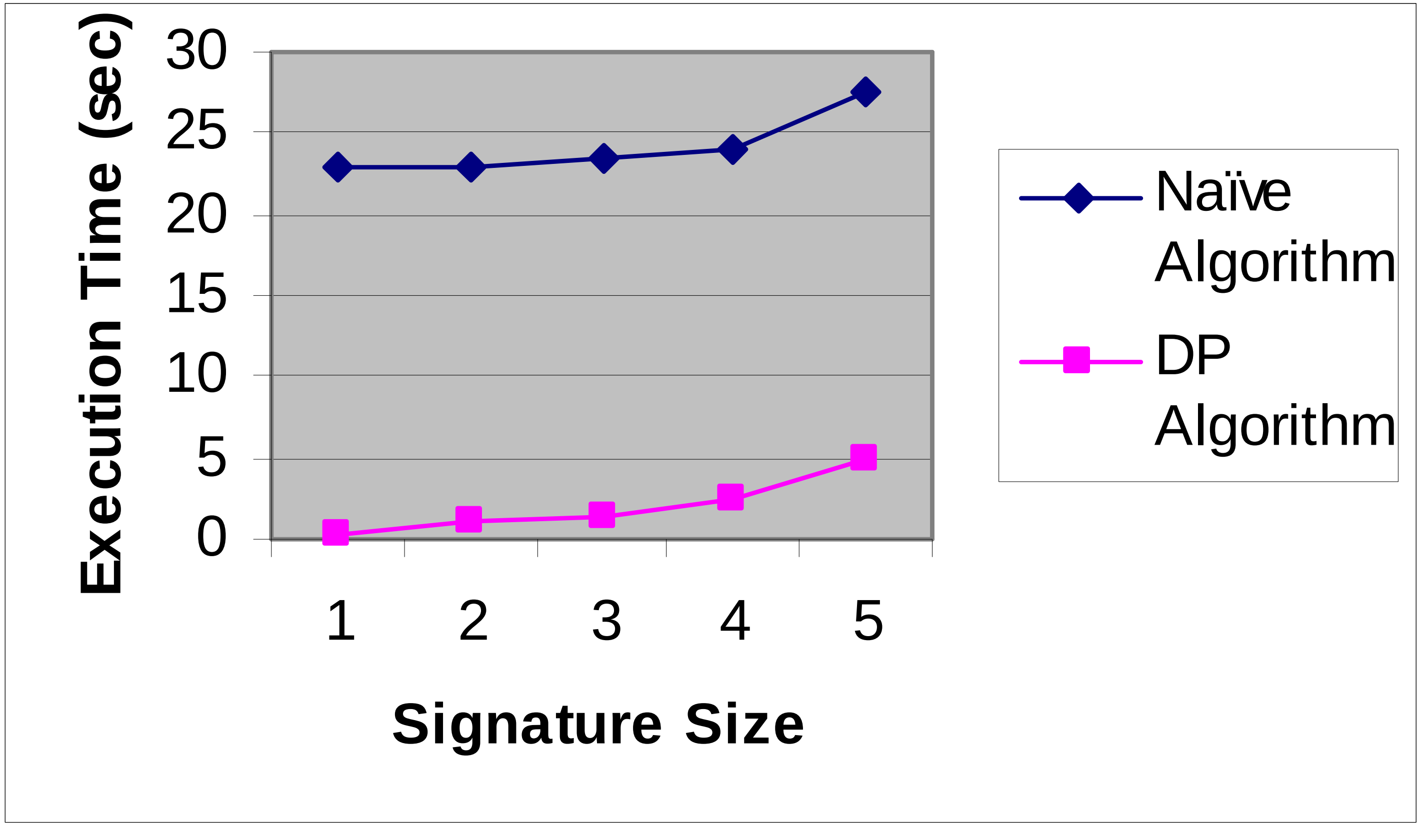



Computing Wavelet Signature



Experiment

Computing Wavelet Signatures



Experiment

Number of Regions per Image

Cluster Epsilon	Avg # of Clusters in YCC	Avg # of Clusters in RGB
0.025	92.9	419.9
0.05	21.9	100.5
0.075	9.9	42.2
0.1	5.8	23.5

Experiment

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Query Response Time (Selectivity)

Querying Epsilon	Response Time (sec)	Avg # of Regions Retrieved	# of Distinct Images
0.05	5.19	15	65
0.06	6.67	49.9	153
0.07	9.42	148.3	344
0.08	13.61	834.9	718
0.09	19.86	890.7	1287

Conclusion

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- Proposed a novel similarity retrieval algorithm that is robust to scaling and translation of objects
- The dynamic programming algorithm for computing wavelets showed an order of magnitude speed up
- The similar images retrieved by WALRUS is semantically more related to the query image