Content-Based Image Retrieval

Selim Aksoy
Department of Computer Engineering
Bilkent University
saksoy@cs.bilkent.edu.tr

Image retrieval

- Searching a large database for images that match a query:
  - What kind of databases?
  - What kind of queries?
  - What constitutes a match?
  - How do we make such searches efficient?

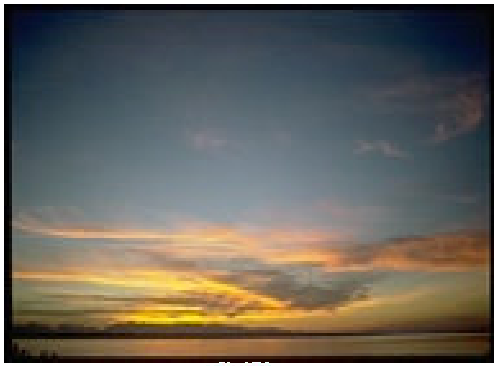
Applications

- Art Collections
  - Fine Arts Museum of San Francisco
- Medical Image Databases
  - CT, MRI, Ultrasound, The Visible Human
- Scientific Databases
  - Earth Sciences
- General Image Collections for Licensing
  - Corbis, Getty Images
- The World Wide Web
  - Google, Microsoft, Flickr

Corel data set

118011
WATER HARBOR
SKY CLOUDS

TIGER CAT WATER GRASS



1090
SUN CLOUDS
WATER SKY

1015
SUN TREE
PLAIN SKY

143078
MOUNTAINS TREES
aspens VALLEY

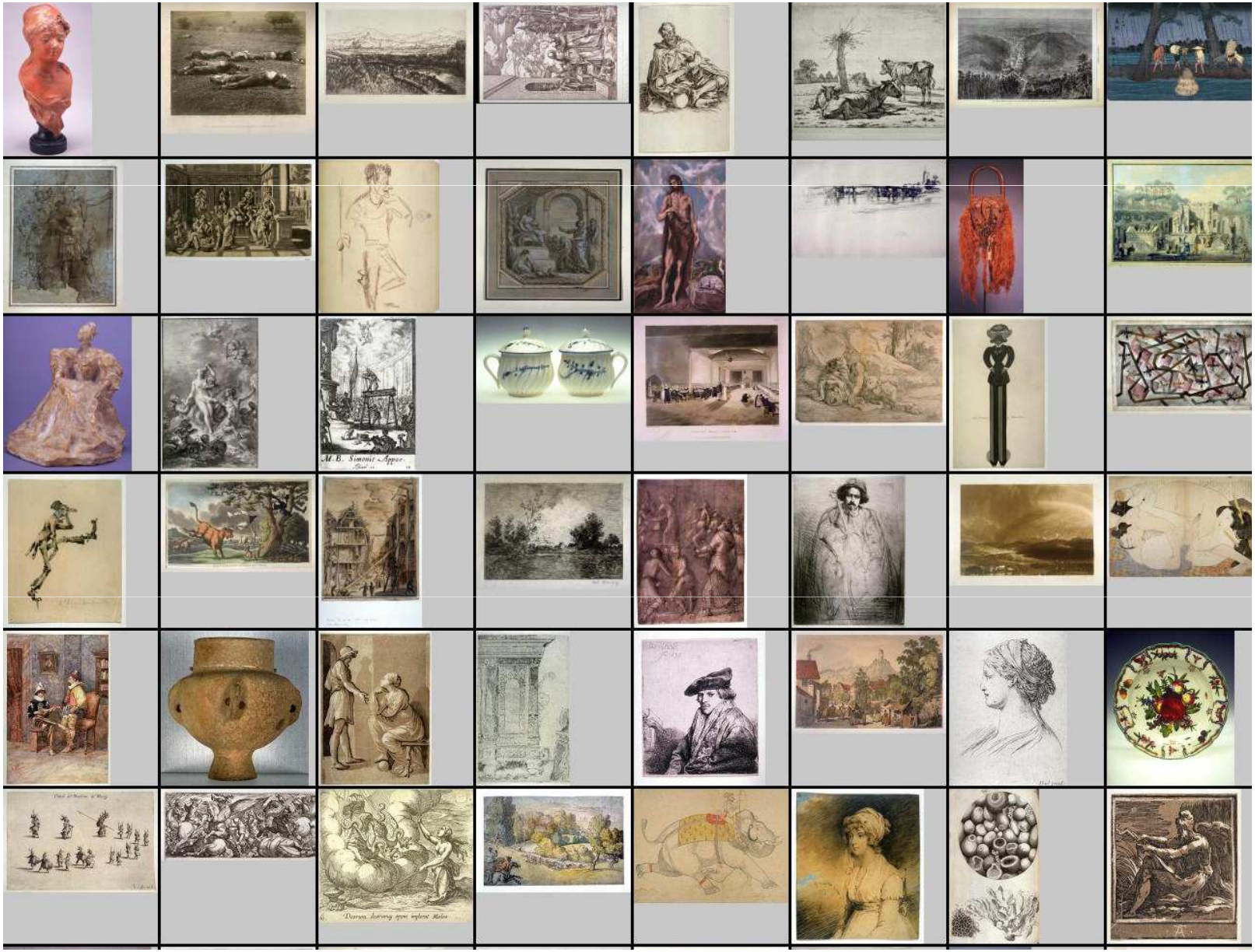
102042
MUSEUM memorial
FLAGS GRASS

119094
GARDEN BUILDING
FLOWERS TREES

131007
GARDEN FLOWERS
HOUSE TREES

60,000 images with annotated keywords

Fine Arts Museum of San Francisco

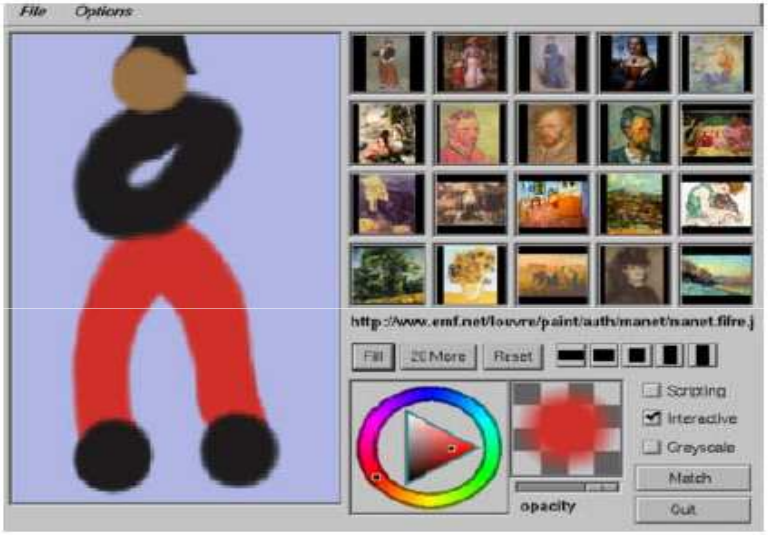


80,000 images

Query formulation

- Text description (keywords)
- Query by example

- Query by sketch



- Symbolic description (man and woman on a beach)
- Relevance feedback

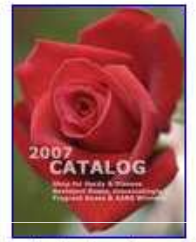
Google query on "rose"

Two-Tone **Rose**
500 x 375 - 95k - jpg
gardening.about.com
[More from z.about.com]

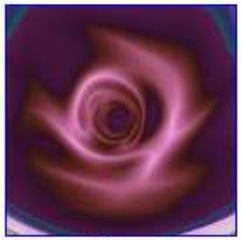
Welcome to the Corpus Christi **Rose** ...
351 x 334 - 51k - gif
www.geocities.com

Frosty **Rose**
600 x 451 - 70k - jpg
blogs.warwick.ac.uk

Dominic Cavendish reviews The **Rose** ...
400 x 313 - 40k - jpg
www.telegraph.co.uk



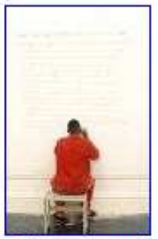
We've been in the business of **rose** .
400 x 539 - 78k - jpg
www.witherspoonrose.com



Rose
512 x 512 - 19k - jpg
www.parabola.me.uk

ROSE Online
800 x 640 - 393k - jpg
www.gameogre.com

Tracey **Rose** The Thinker, 1996
500 x 451 - 26k - jpg
www.artthrob.co.za



Tracey **Rose** Span II, 1997
317 x 500 - 18k - jpg
www.artthrob.co.za

The **rose** apple is occasionally ...
350 x 307 - 57k - jpg
www.tradewindsfruit.com

Lewis **Rose** also known as Lewis N. ...
347 x 348 - 18k - jpg
lewisrose.com

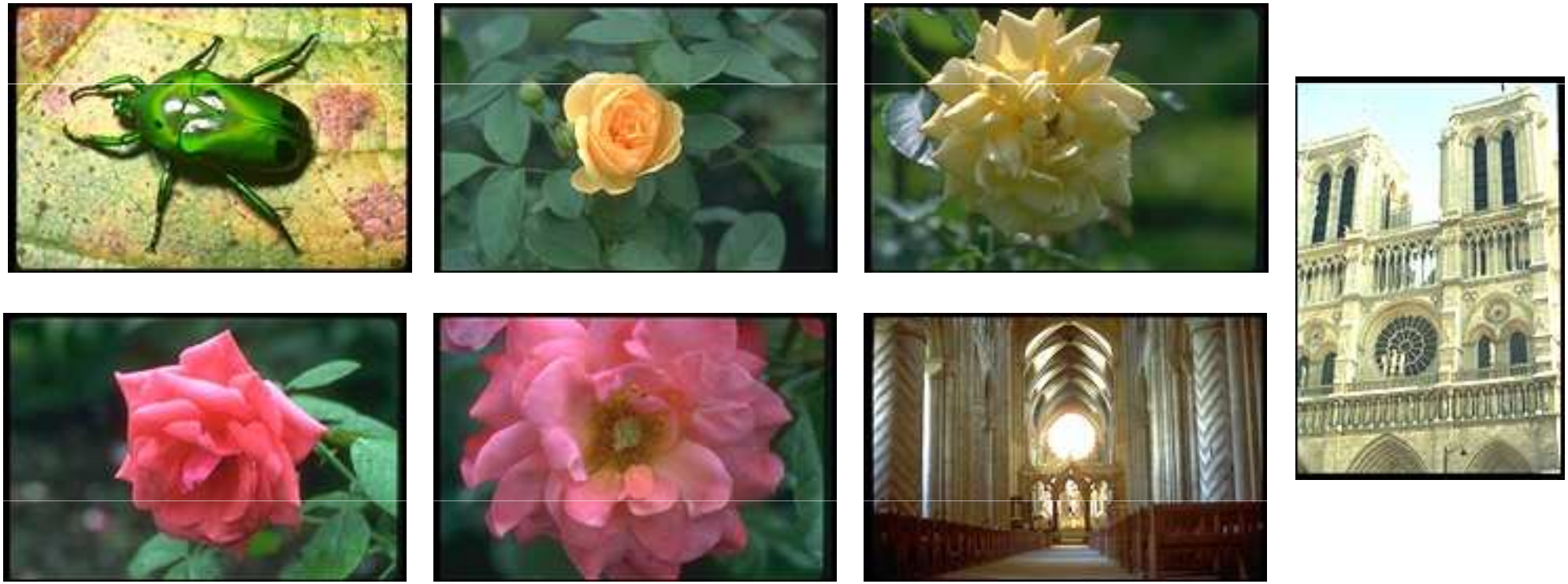
Rose Parade Seating Chart Seating ...
449 x 354 - 18k - gif
www.barrystickets.com

Rose Quartz point shape in Sterling ...
456 x 478 - 15k - jpg
www.wehug.com

The Exorcism of Emily **Rose**
300 x 375 - 29k
www.smh.com.au

rose rose 6499 hits
574 x 576 - 33k - jpeg
www.firstmonday.org

Corel query on “rose”



Corbis query on "rose"

42-17895937 (RM)
Season of Perfume by Yang Ping
Yang Ping
» Price Image
☐ Lightbox ☐ Cart

42-17895408 (RM)
Autumn Beauties by Wang Chingho
Wang Chingho
» Price Image
☐ Lightbox ☐ Cart

42-17895882 (RM)
Little Black Cat by Wu Yeizhao
Wu Yeizhao
» Price Image
☐ Lightbox ☐ Cart

42-17860276 (RM)
Home by Hugh Shurley
Hugh Shurley
Hugh Shurley
» Price Image
☐ Lightbox ☐ Cart

42-17895421 (RM)
Butterflies Among Flowers by Wang Chingho
Wang Chingho
» Price Image
☐ Lightbox ☐ Cart

42-17895445 (RM)
Red Roses by Lu Bisa
Lu Bisa
» Price Image
☐ Lightbox ☐ Cart

42-17895962 (RM)
Beautiful Flowers by Cao Jingen
Cao Jingen
» Price Image
☐ Lightbox ☐ Cart

42-16247767 (RM)
Peppers Stuffed with Rosebuds
J.Bilic
» Price Image
☐ Lightbox ☐ Cart

42-18240866 (RM)
David Bowie Smoking Cigarette
1976
Steve Schapiro
» Price Image
☐ Lightbox ☐ Cart

42-17165934 (RM)
Woman Taking a Bath in Rose Petals
Fendis
» Price Image
☐ Lightbox ☐ Cart

42-16246447 (RM)
Oriental-Style Litchi Salad
J.Riou
» Price Image
☐ Lightbox ☐ Cart

42-16801960 (RM)
Bouquet of Red Roses
May 27, 2005
Owen Franken
» Price Image
☐ Lightbox ☐ Cart
› See Image Set(s)

42-16801959 (RM)
Bouquet of Red Roses
May 27, 2005
Owen Franken
» Price Image
☐ Lightbox ☐ Cart

42-16801939 (RM)
Bouquet of Red Roses
May 27, 2005
Owen Franken
» Price Image
☐ Lightbox ☐ Cart

42-17529104 (RM)
Rose Red #9 Series by Elisa Lazo de Valdez
April 1, 2006
Elisa Lazo de Valdez
» Price Image
☐ Lightbox ☐ Cart

42-17529137 (RM)
Rose Red #46 Series by Elisa Lazo de Valdez
April 1, 2006
Elisa Lazo de Valdez
» Price Image
☐ Lightbox ☐ Cart

42-17529136 (RM)
Rose Red #57 Series by Elisa Lazo de Valdez
April 1, 2006
Elisa Lazo de Valdez
» Price Image

42-15766292 (RM)
Roses in Kohinoor Suite Bathroom at Amarvilas...
January 31, 2003
Remi Benali
» Price Image

42-16249149 (RM)
Stuffed Red Onions
C.Fleurent
» Price Image
☐ Lightbox ☐ Cart

42-15944324 (RM)
Bridal Bouquet
2005
Robert Levin
» Price Image
☐ Lightbox ☐ Cart

42-16248521 (RM)
Red Onion
J.Garcia
» Price Image
☐ Lightbox ☐ Cart

42-16248491 (RM)
Sliced Red Onion
J.Garcia
» Price Image
☐ Lightbox ☐ Cart

42-16246499 (RM)
Glass of Rose Wine
G.Flayols
» Price Image
☐ Lightbox ☐ Cart

42-15766394 (RM)
Rose Petal Bath at Vanyavilas Resort
January 31, 2003
Remi Benali
» Price Image

Difficulties with keywords

- Images may not have keywords.
  - (An image is worth … how many key-words?)
- Query is not easily satisfied by keywords.
  - "A casually dressed couple gazing into each others eyes lovingly with dramatic clouds in the background."
  - "Pretty girl doing something active, sporty in a summery setting, beach - not wearing lycra, exercise clothes - more relaxed in tee-shirt. Feature is about deodorant so girl should look active - not sweaty but happy, healthy, carefree - nothing too posed or set up - nice and natural looking."
- Content-based image retrieval (CBIR)

Content-based image retrieval

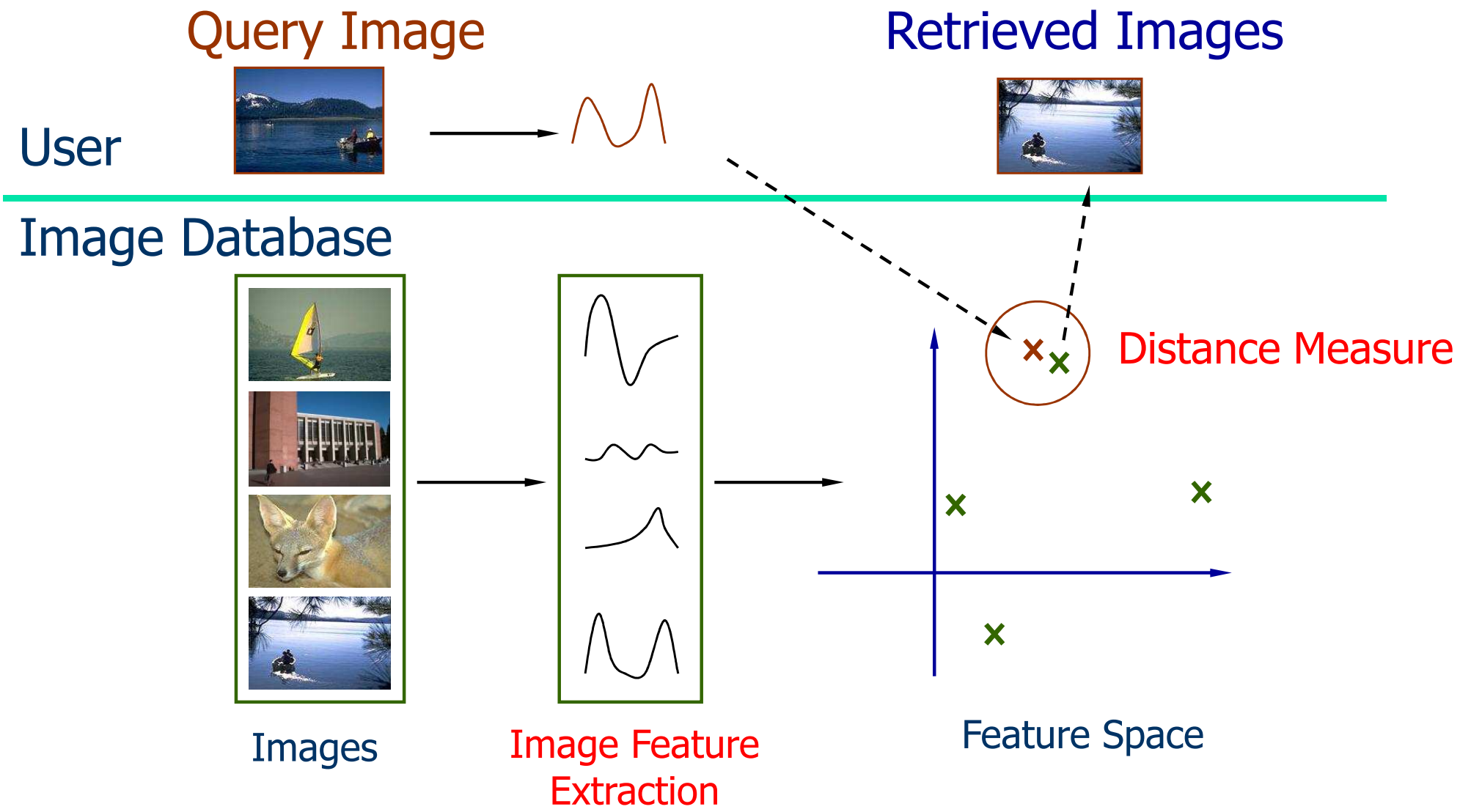


Image representations and features

- Image representations:
  - Iconic
  - Global
  - Region-based
  - Object-based
- Image features:
  - Color
  - Texture
  - Shape
  - Objects and their relationships
    (this is the most powerful, but you have to be able to recognize the objects!)

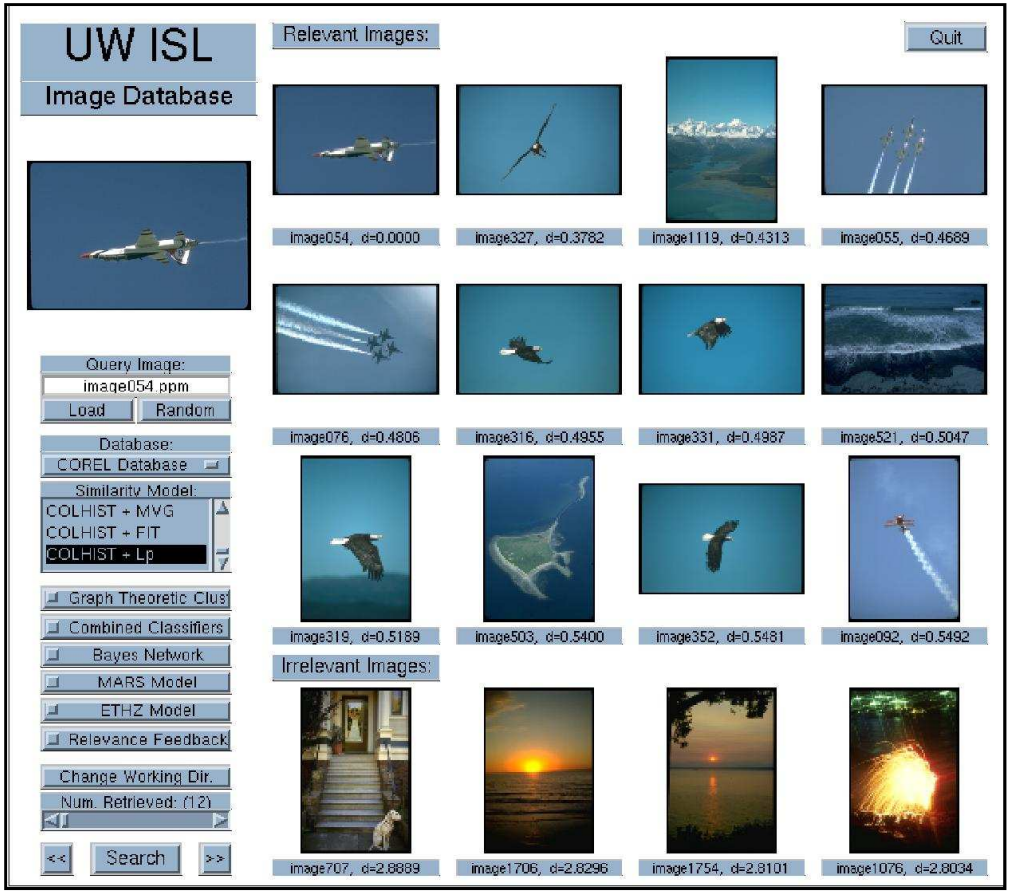
Image similarity

- Distance measures:
  - Euclidean distance
  - Other L_p metrics
  - Histogram intersection
  - Cosine distance
  - Earth mover's distance
- Probabilistic similarity measures:
  - P(relevance | two images)
  - P(relevance | two images) / P(irrelevance | two images)

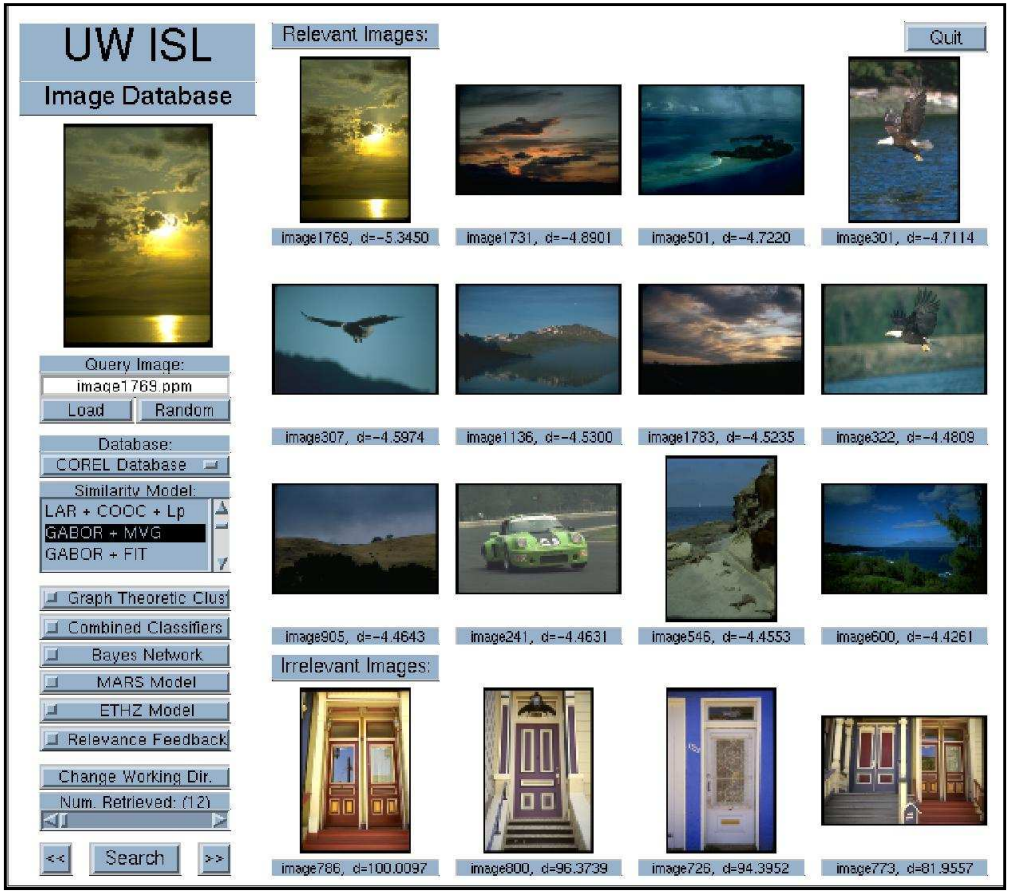
Global histograms

- Searching using global color histograms

Global histograms

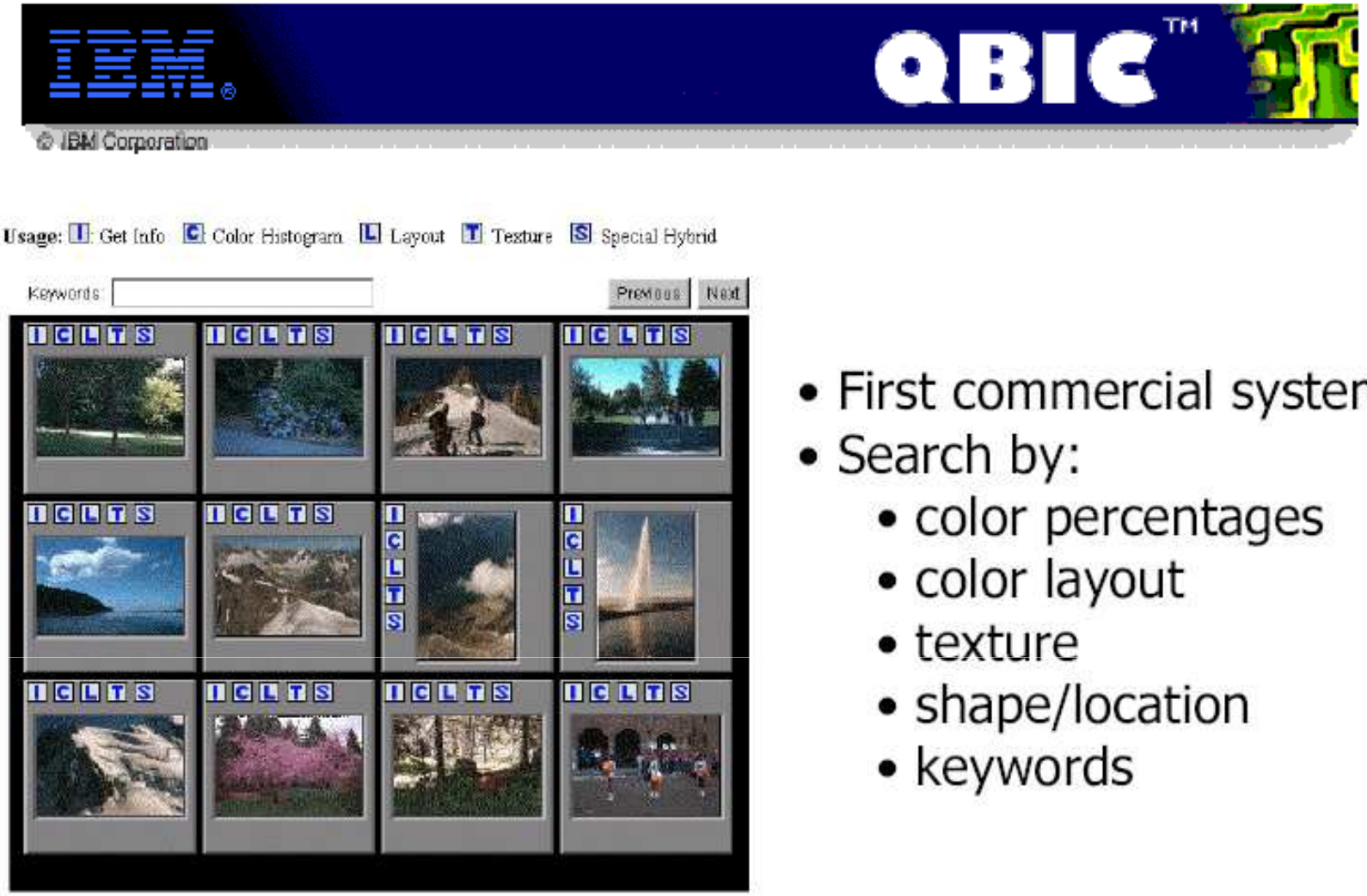


"Airplanes" using color histograms (4/12)



"Sunsets" using Gabor texture (3/12)

Query by image content (QBIC)



- First commercial system
- Search by:
  - color percentages
  - color layout
  - texture
  - shape/location
  - keywords

Try their demo: http://wwwqbic.almaden.ibm.com

Color histograms in QBIC

- The QBIC color histogram distance is:

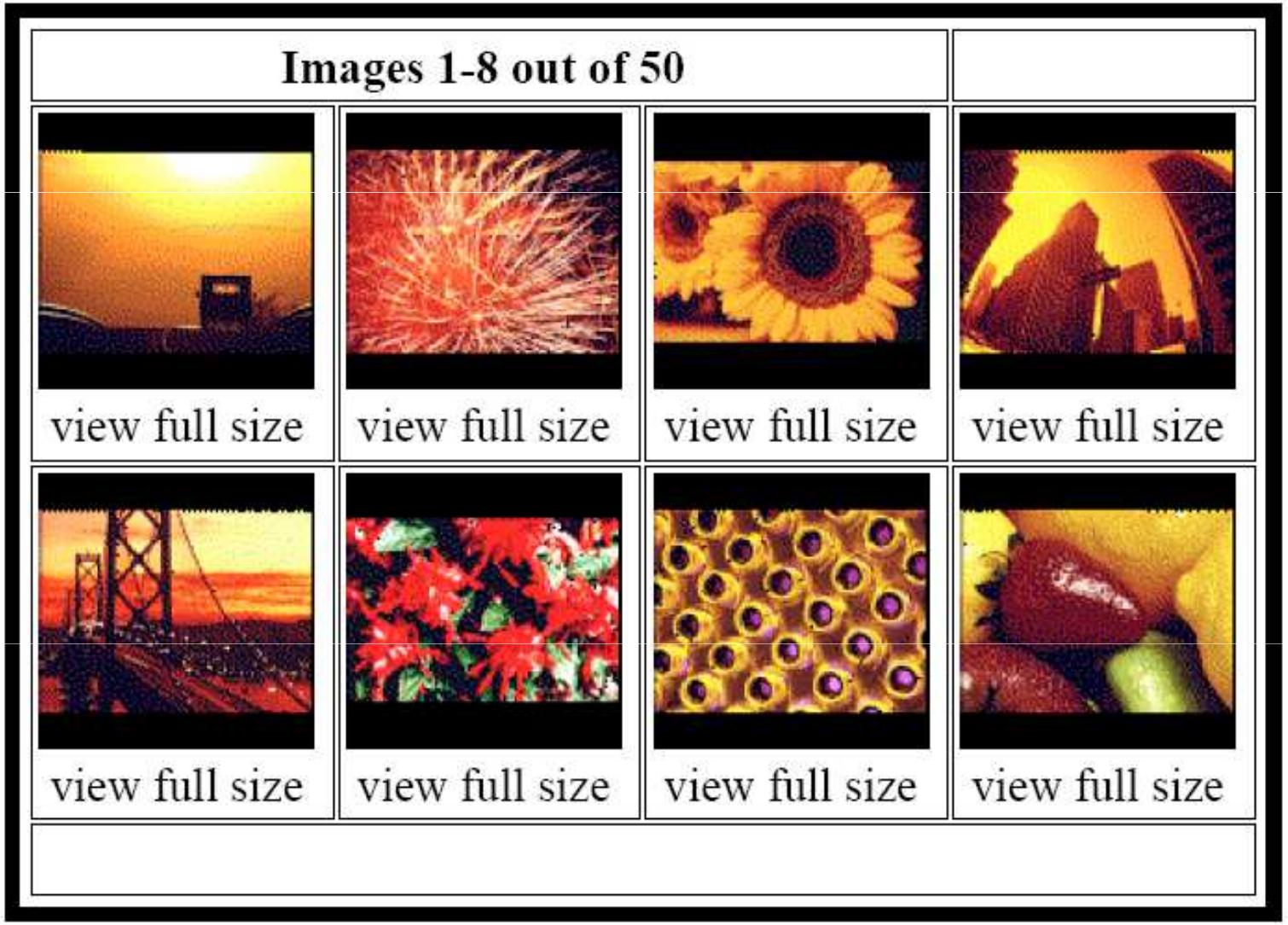
$$d_{hist}(I,Q) = (h(I) - h(Q))^T A (h(I) - h(Q)).$$

- h(I) is a K-bin histogram of a database image.
- h(Q) is a K-bin histogram of the query image.
- A is a K x K similarity matrix.

	R	G	B	Y	C	V
R	1	0	0	.5	0	.5
G	0	1	0	.5	.5	0
B	0	0	1			?
Y				1		?
C		?			1	
V						1

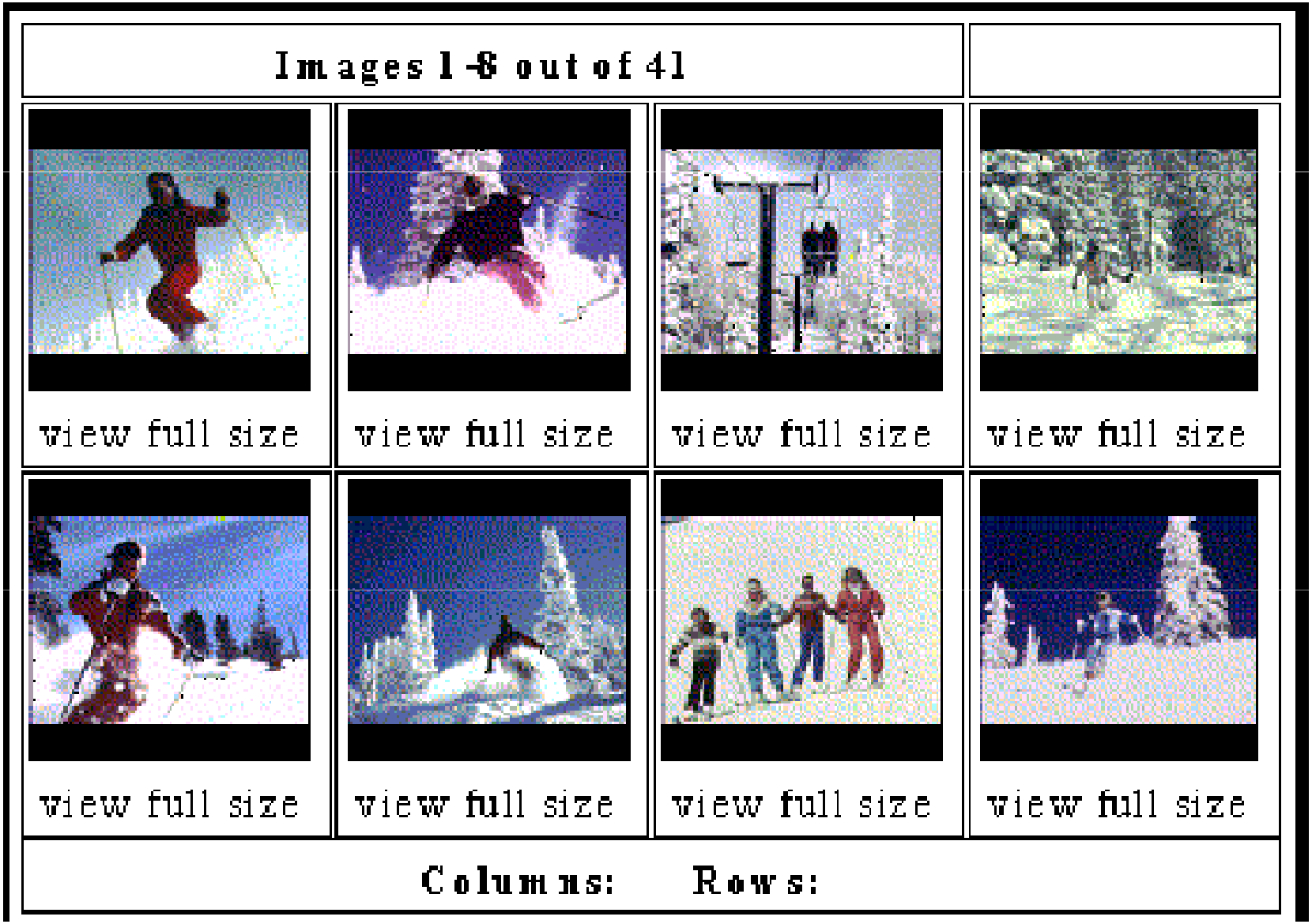
How similar is blue to cyan?

Color percentages in QBIC



%40 red, %30 yellow, %10 black

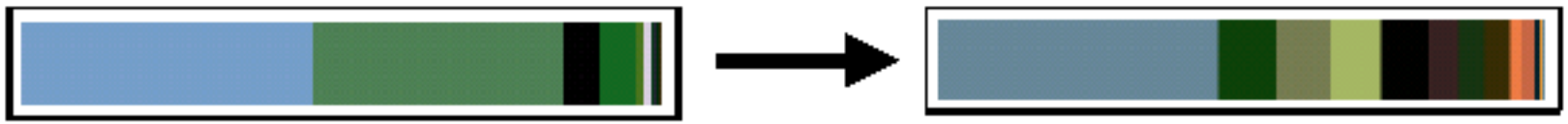
Color layout in QBIC



Earth mover's distance

For each image, compute color signature:

Define distance between two color signatures to be the minimum amount of "work" needed to transform one signature into another.



Earth mover's distance

- Visualization using EMD and multidimensional scaling

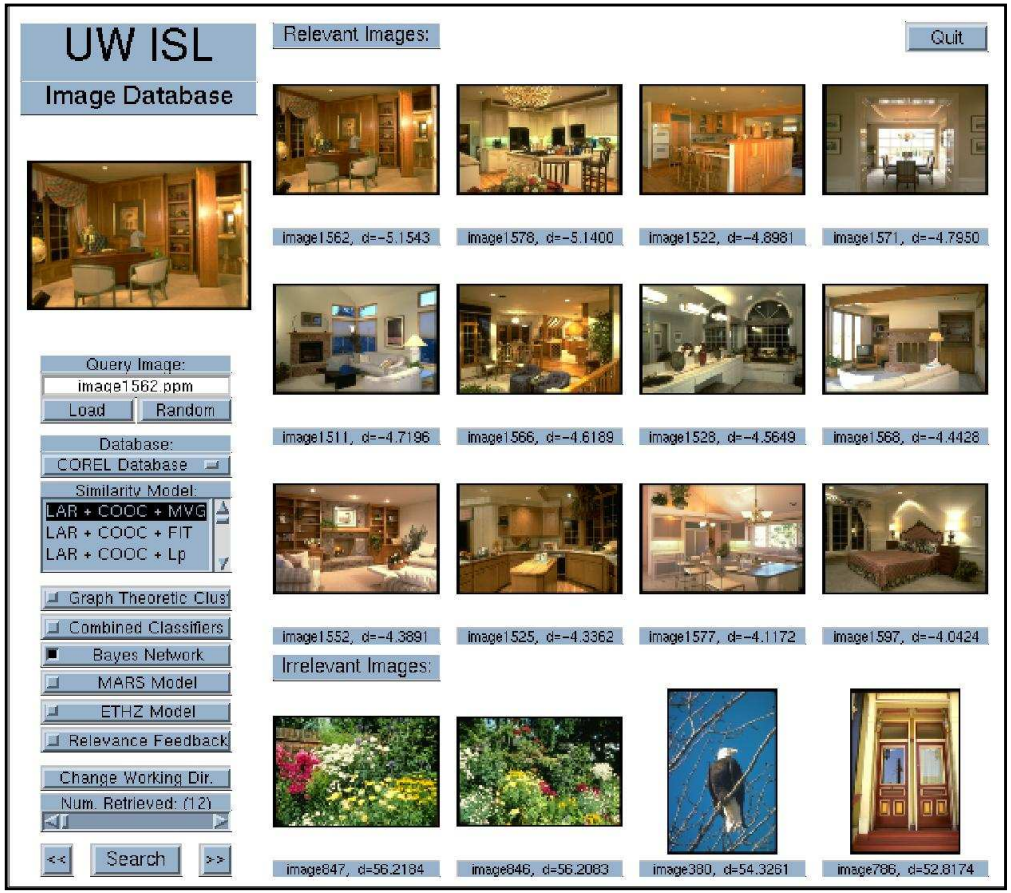
Probabilistic similarity measures

- Two classes:
  - Relevance class A
  - Irrelevance class B
- Bayes classifier
  - Assign (ξ_i, ξ_j) to $\begin{cases} \text{A if } P(A|(\xi_i,\xi_j)) > P(B|(\xi_i,\xi_j)) \\ \text{B otherwise} \end{cases}$
- Discriminant function for classification

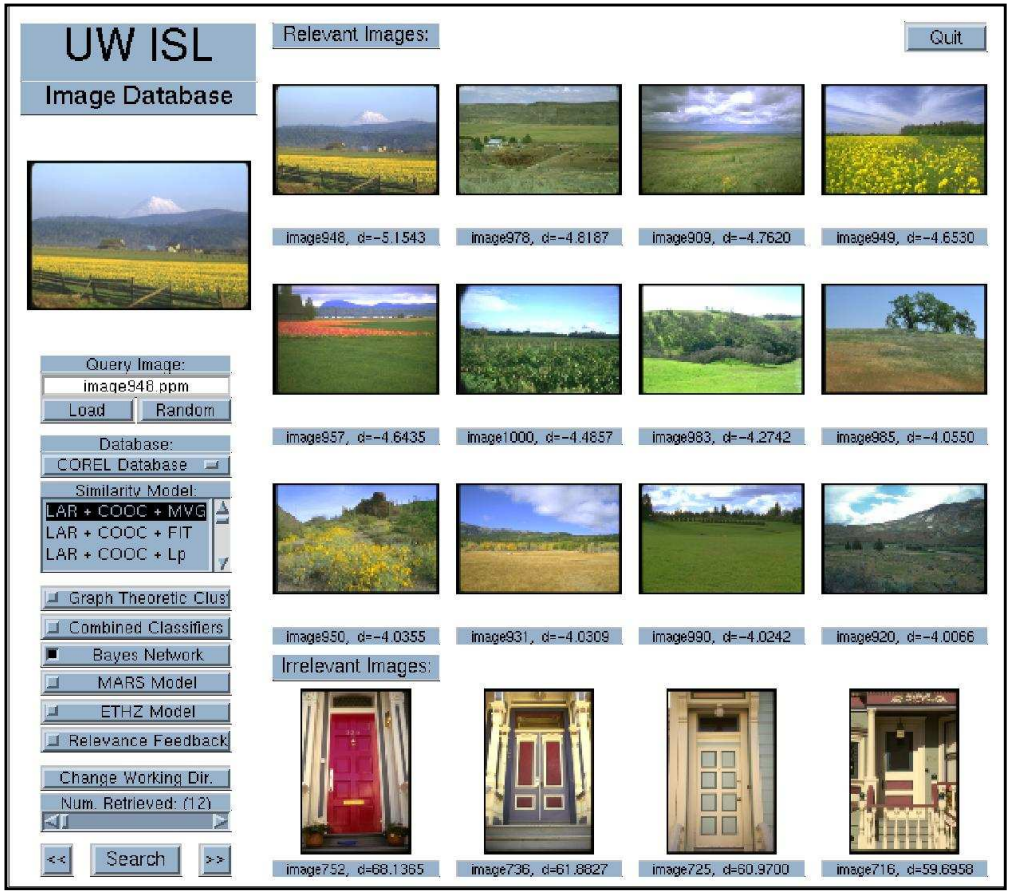
$$\Delta(\xi_i,\xi_j) = \frac{P(A|(\xi_i,\xi_j))}{P(B|(\xi_i,\xi_j))} = \frac{P((\xi_i,\xi_j)|A)\,P(A)}{P((\xi_i,\xi_j)|B)\,P(B)}$$

- Rank images according to posterior ratio values based on feature differences.

Probabilistic similarity measures

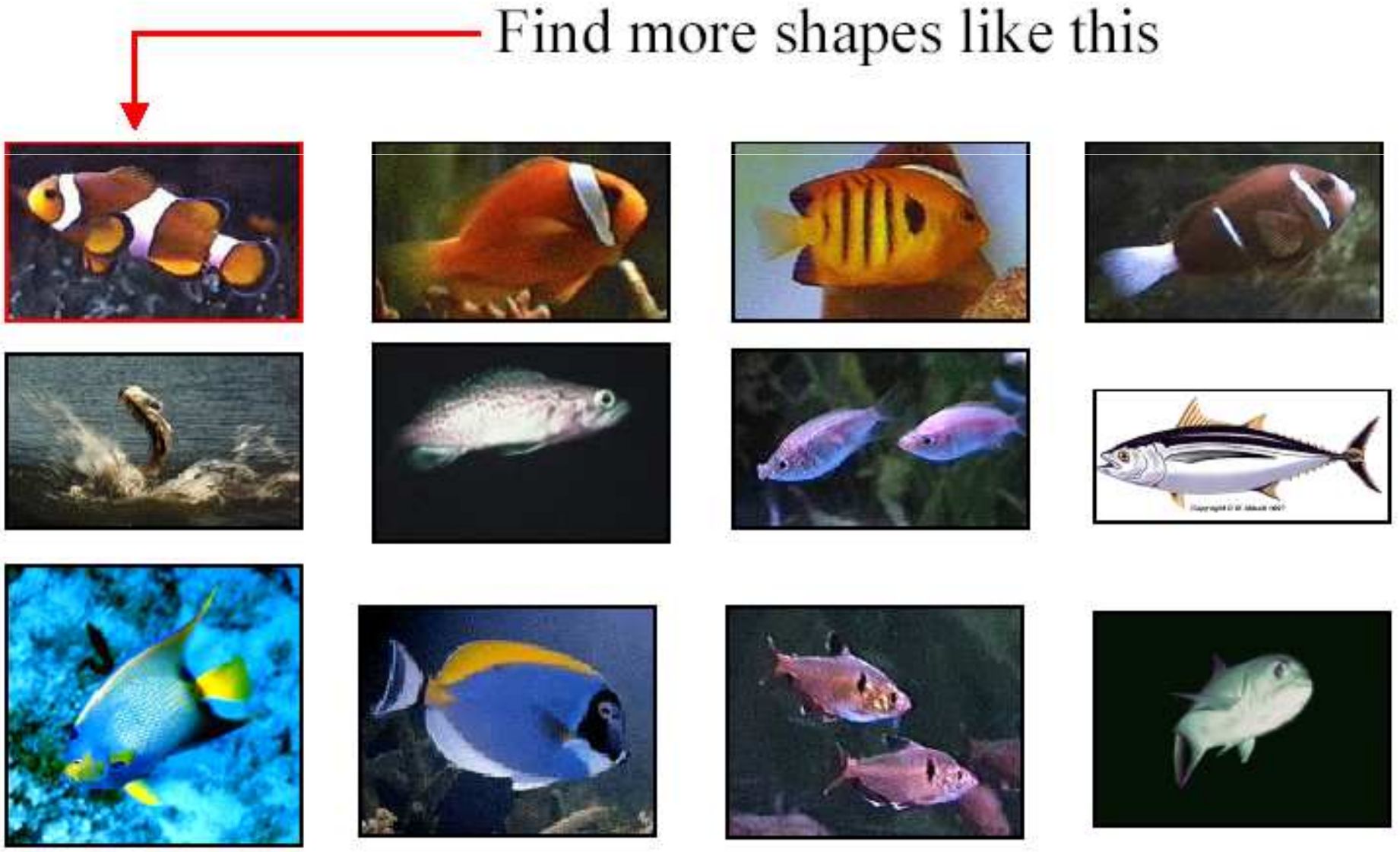


"Residential interiors" (12/12)

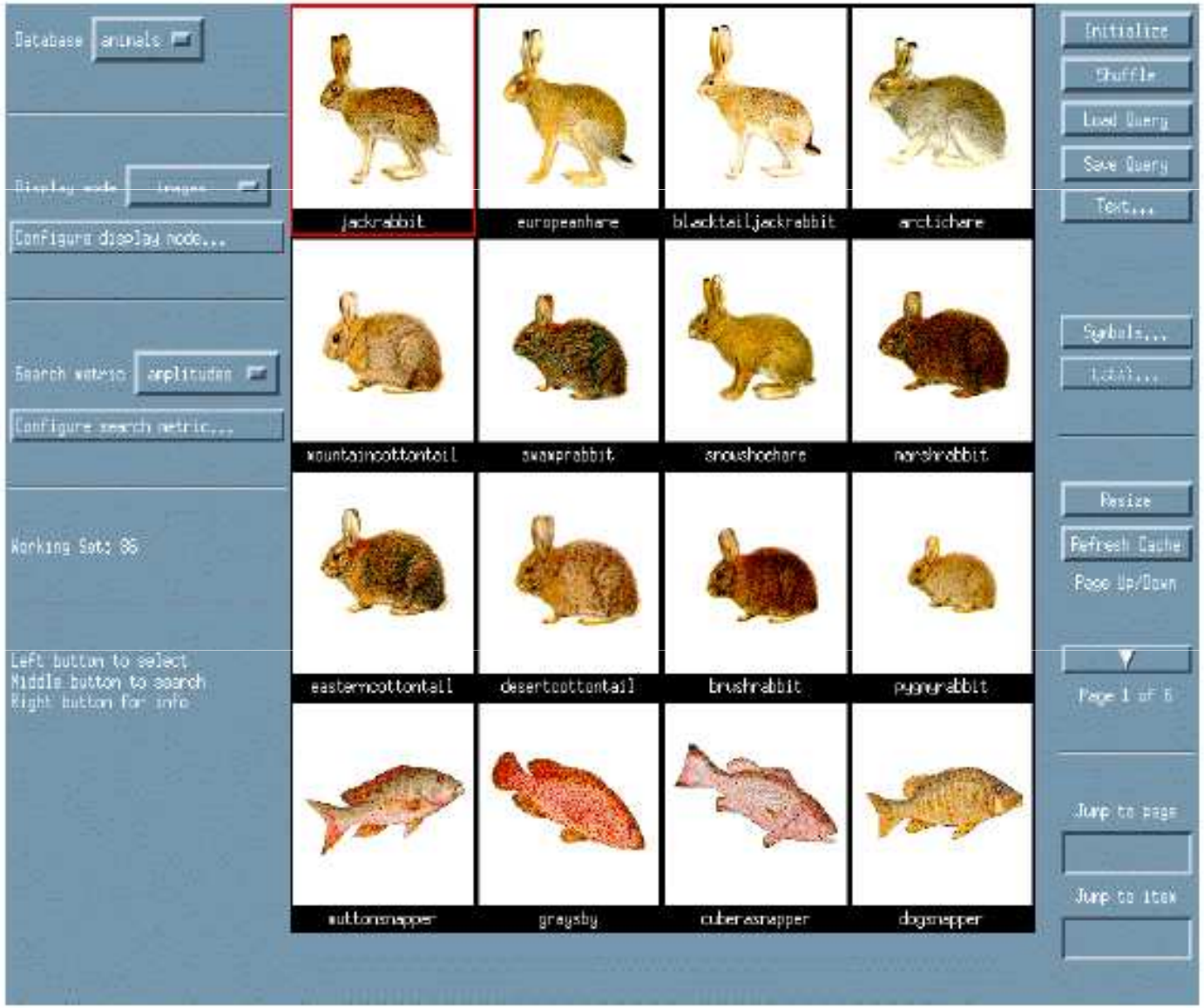


"Fields" (12/12)

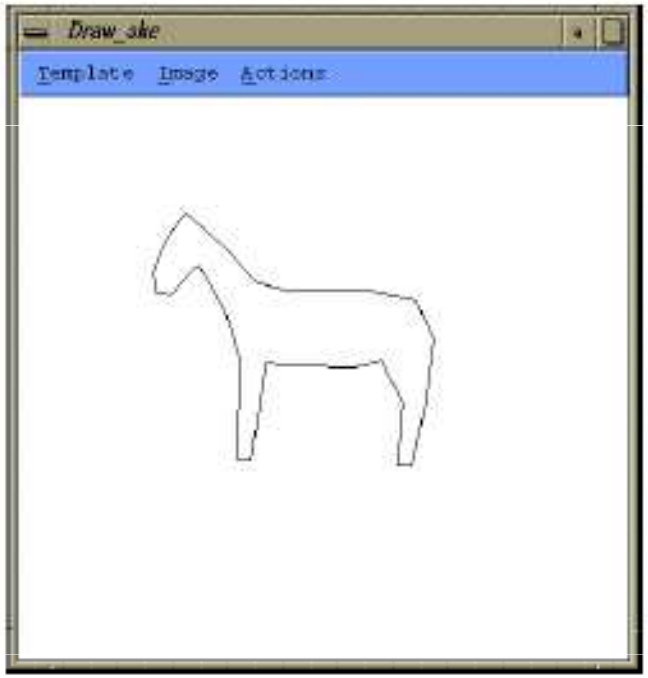
Shape-based retrieval



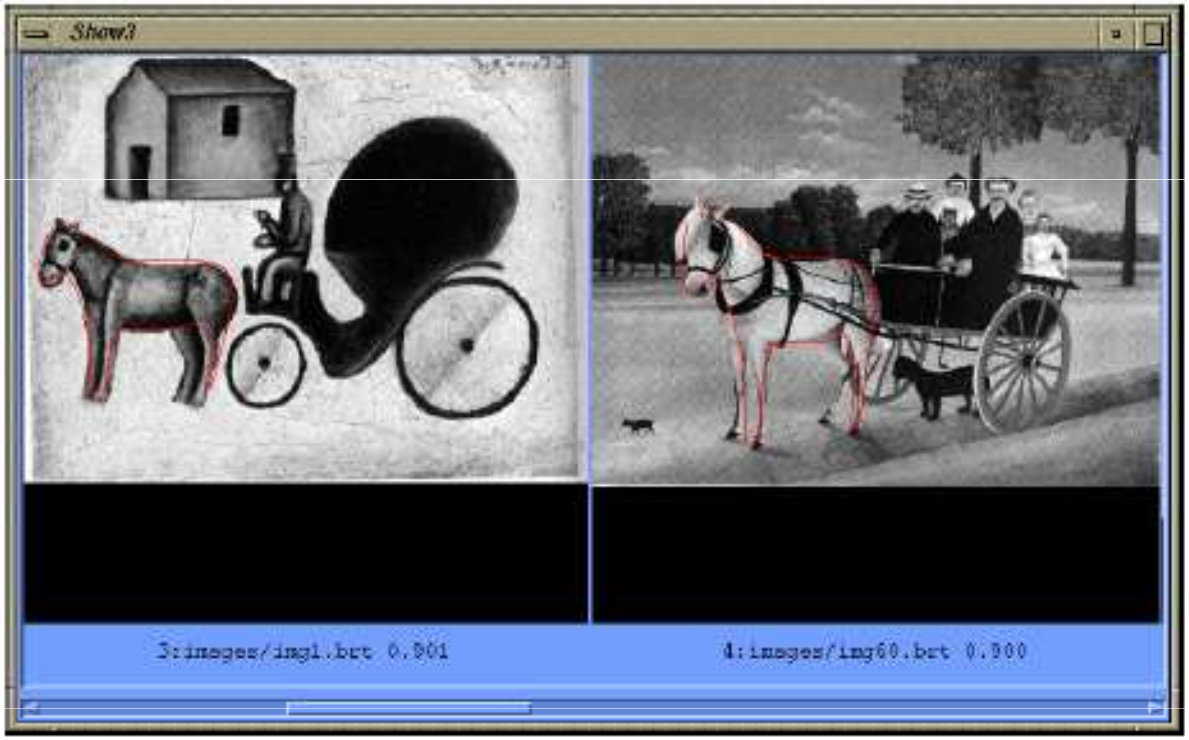
Shape-based retrieval



Elastic shape matching



Sketch-based query



retrieved images

Iconic matching

Example applications:

- Copyright and trademark protection
- Duplicate removal
- Linking images used in evidence, for example child pornography

Problems in finding "exact" matches:

- Lossy compression, image scanning
- Color space conversion
- Photoshop-style transforms: blur, scale, rotate, warp, crop, cut, etc.

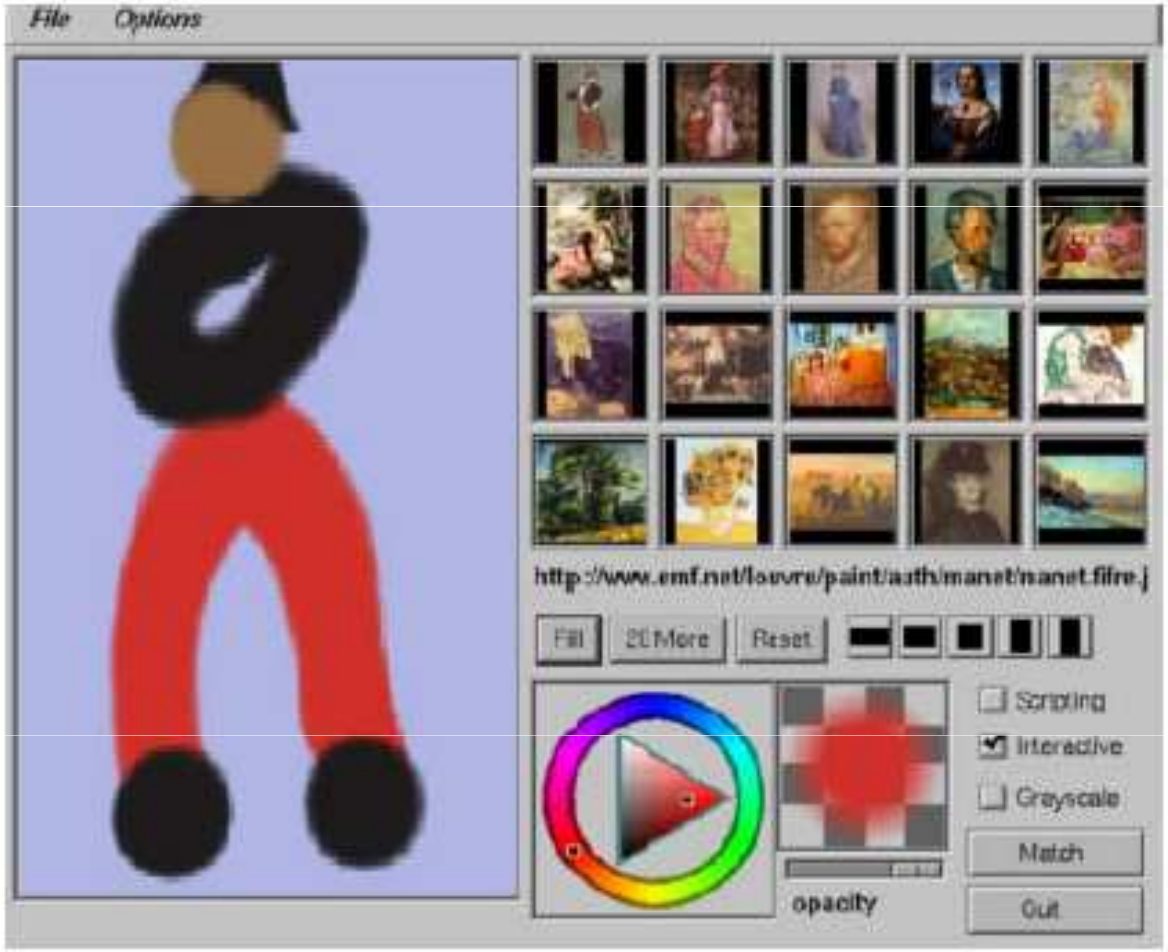
Iconic matching

- Wavelet-based image compression
- Quantization of coefficients

painted scanned target

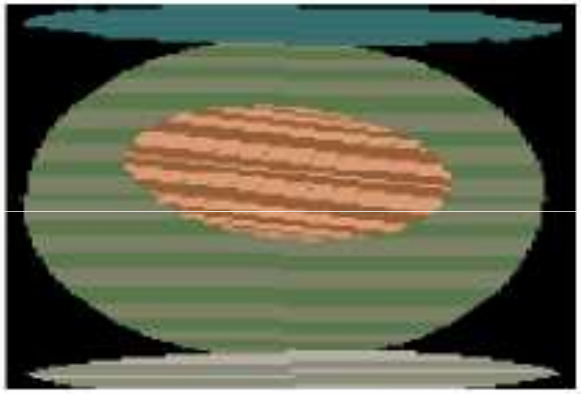
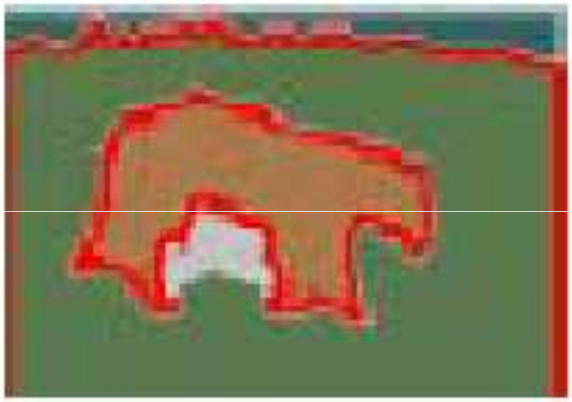
From Jacobs, Finkelstein, & Salesin
Fast Multi-Resolution Image Querying, SIGGRAPH 1995

Iconic matching



Example taken from Jacobs, Finkelstein, & Salesin
Fast Multi-Resolution Image Querying, SIGGRAPH 1995

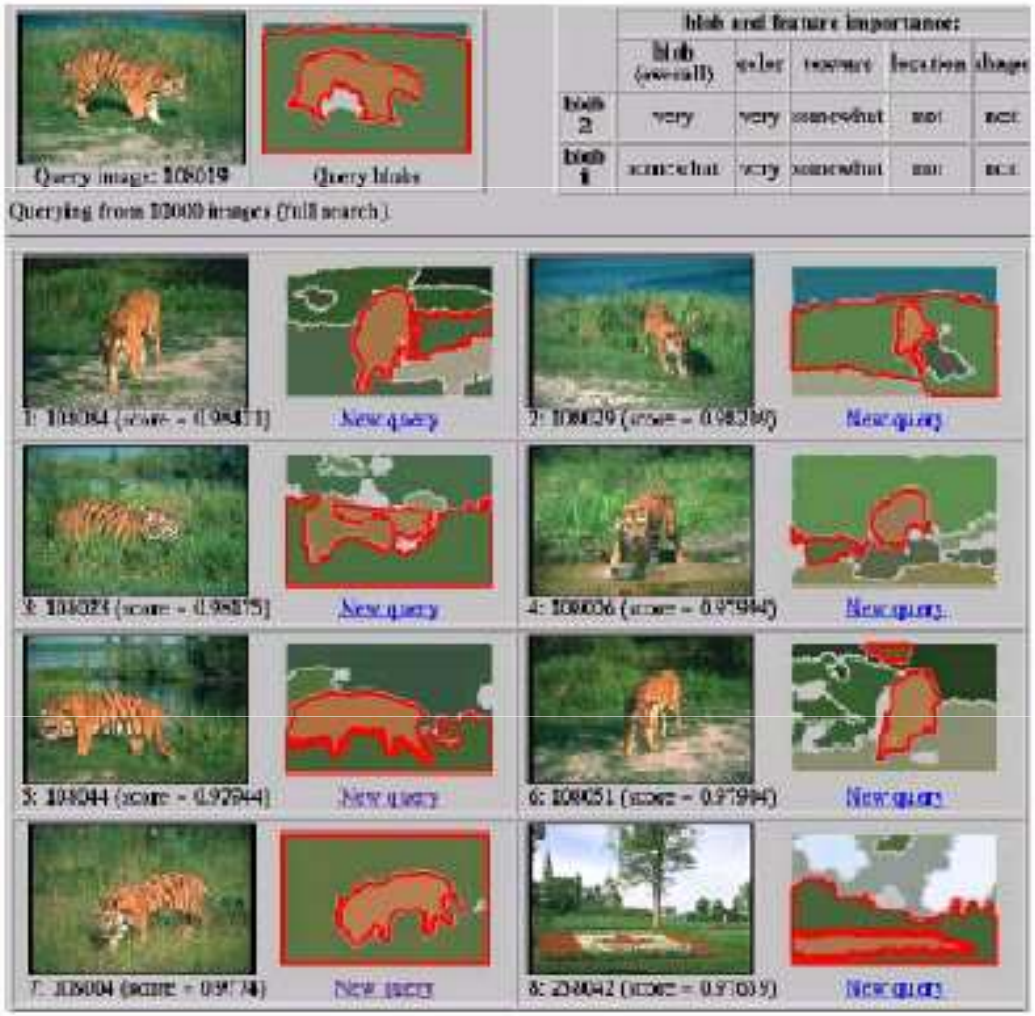
Region-based retrieval: Blobworld

- Images are segmented on color plus texture
- User selects a region of the query image
- System returns images with similar regions
- Works really well for tigers and zebras

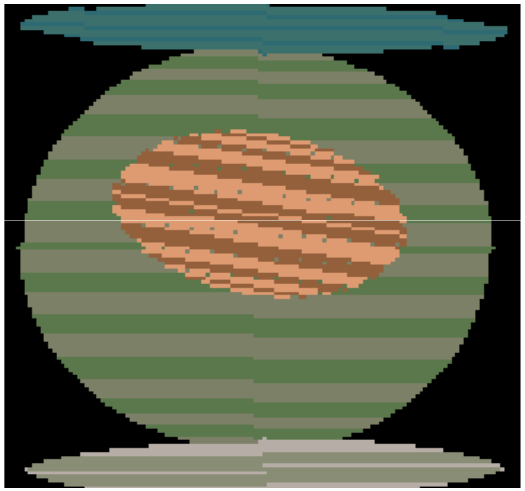
Demo: http://elib.cs.berkeley.edu/photos/blobworld

Region-based retrieval: Blobworld



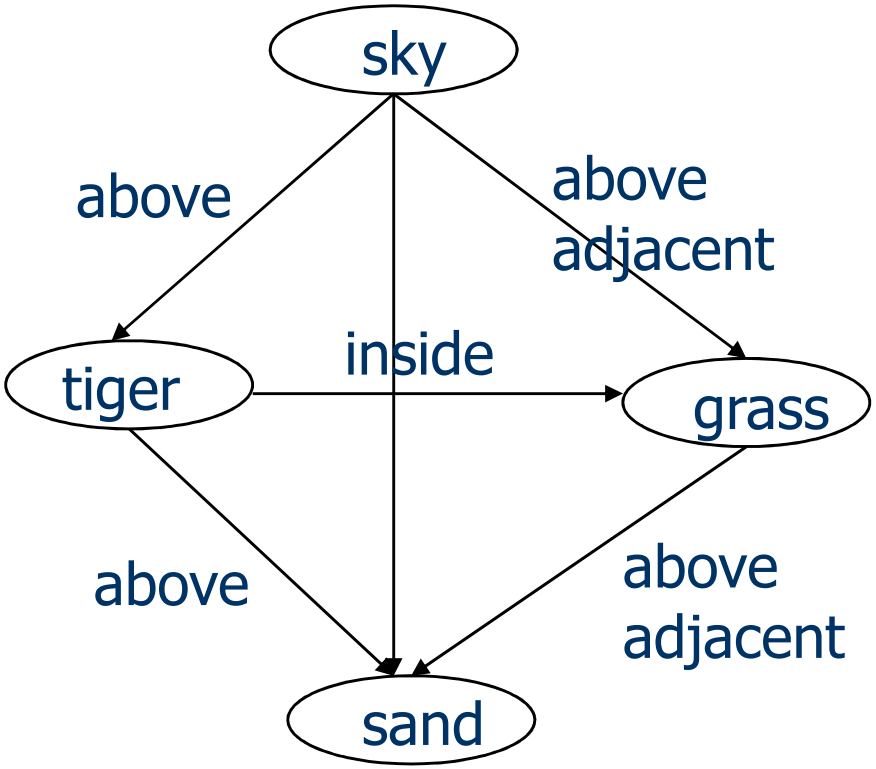
Retrieval using spatial relationships

image



abstract regions

- Build graph using regions and their spatial relationships.
- Similarity is computed using graph matching.



Combining multiple features

Text query
on
"rose"

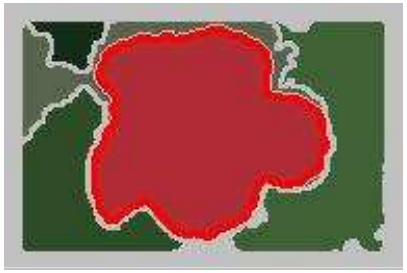






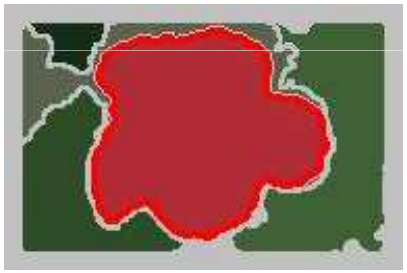
Combining multiple features

Visual query on



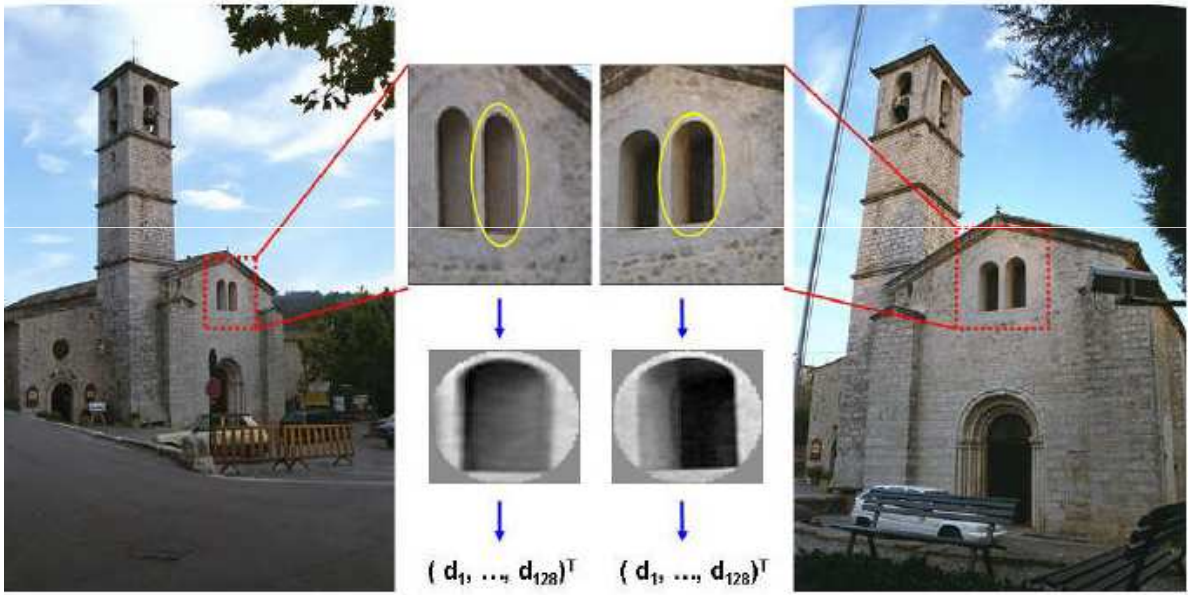
Combining multiple features

Text query
on
"rose"
and visual query
on

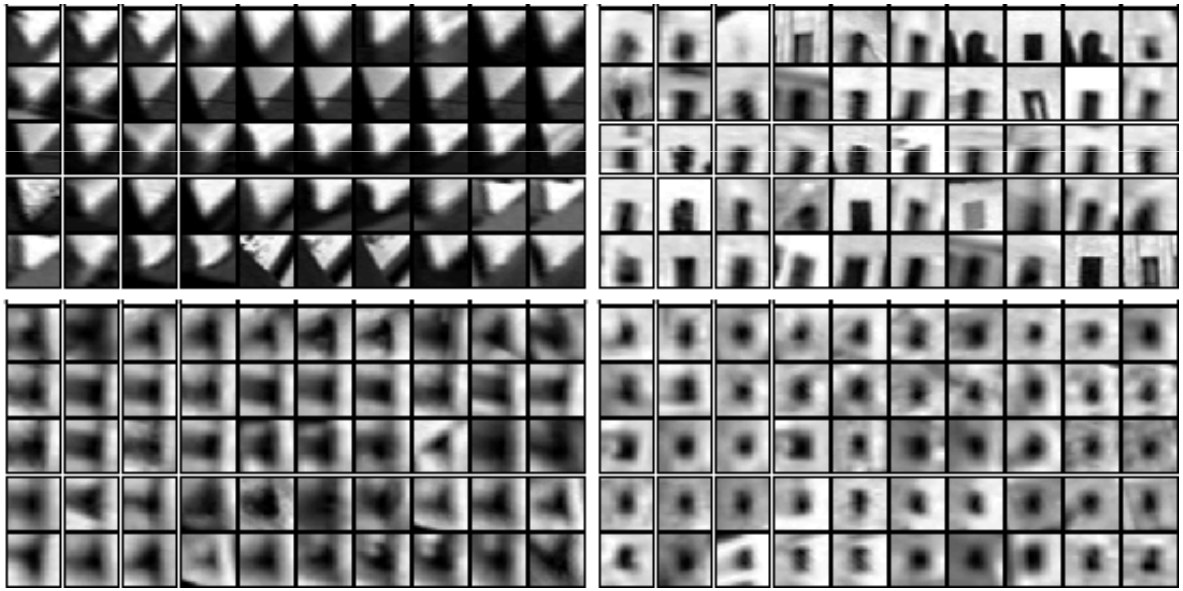


Video Google: object matching

Video Google



Viewpoint invariant descriptors



Visual vocabulary

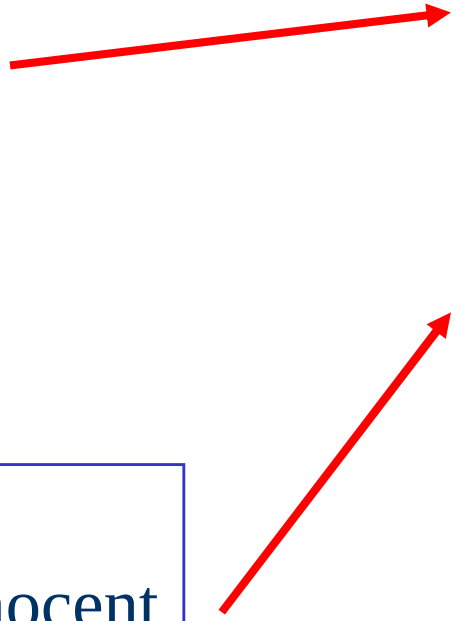
Video Google

Document 1

Now is the time for all good men to come to the aid of their country.

Document 2

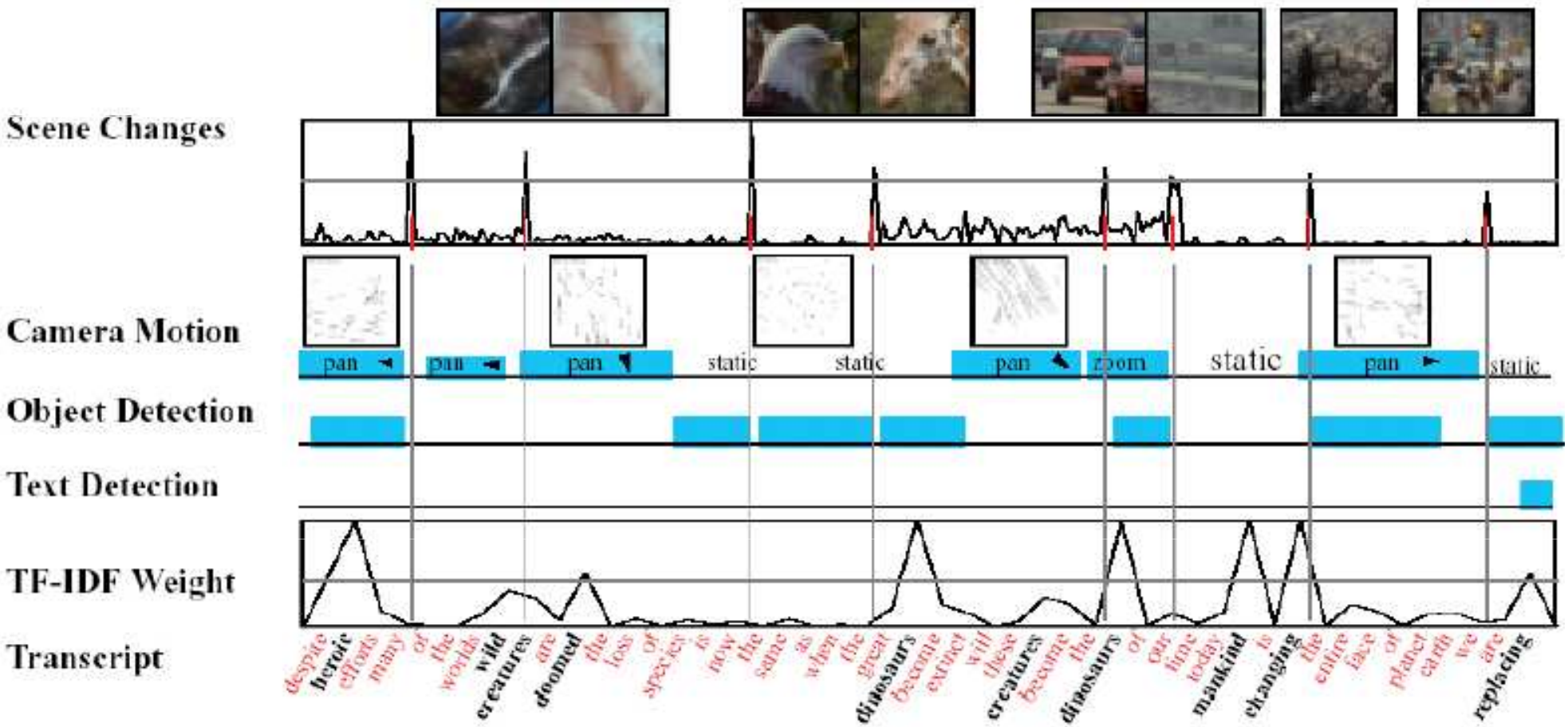
Summer has come and passed. The innocent can never last.



Inverted index

Word	Document
aid	1
all	1
and	2
can	2
come	1, 2
country	1
for	1
good	1
…	…
the	1, 1, 2
…	…

Video skimming

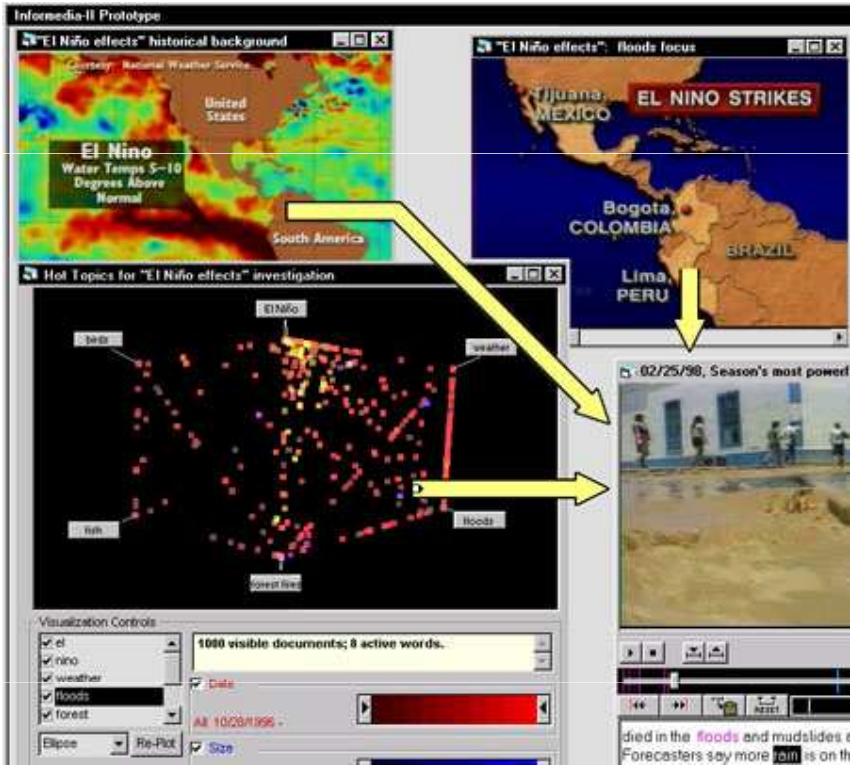


Event detection, indexing, retrieval

Assign semantic labels to significant events in video:

- Explosion, car crash, door slam (audio/video track)
- Marilyn Monroe enters scene
- Pele scores goal
- Jay Leno tells joke and then delivers punch-line
- Two people exchange a briefcase in park
- etc.

Informedia Digital Video Library



IDVL interface returned for "El Nino" query along with different multimedia abstractions from certain documents.

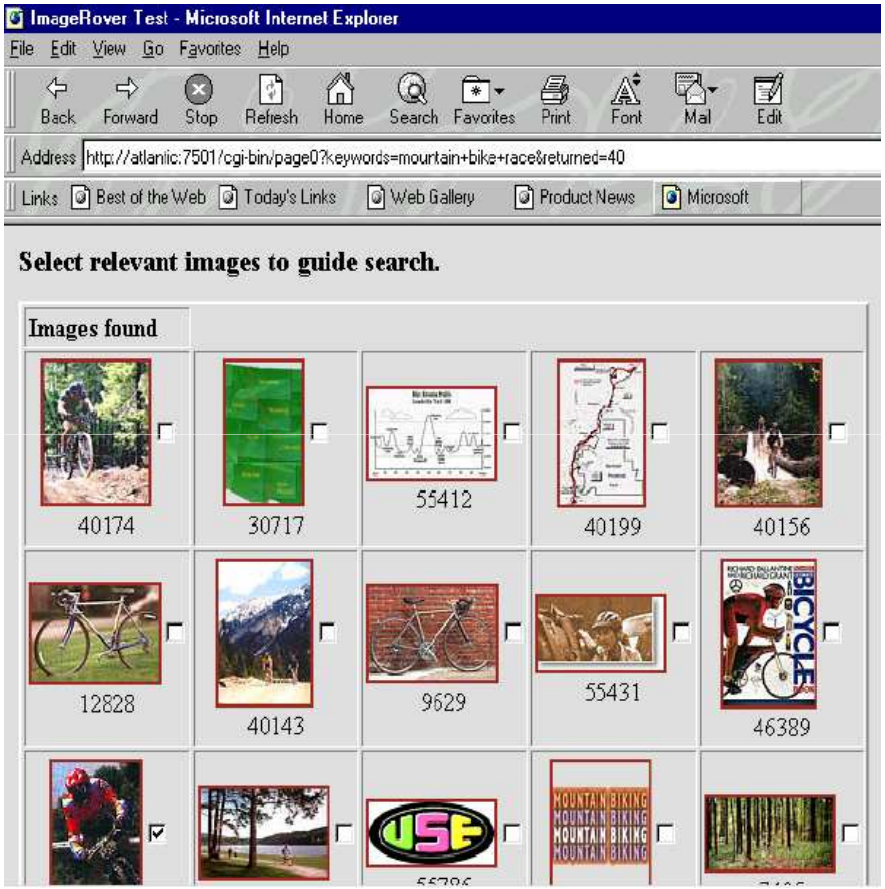
Informedia Digital Video Library

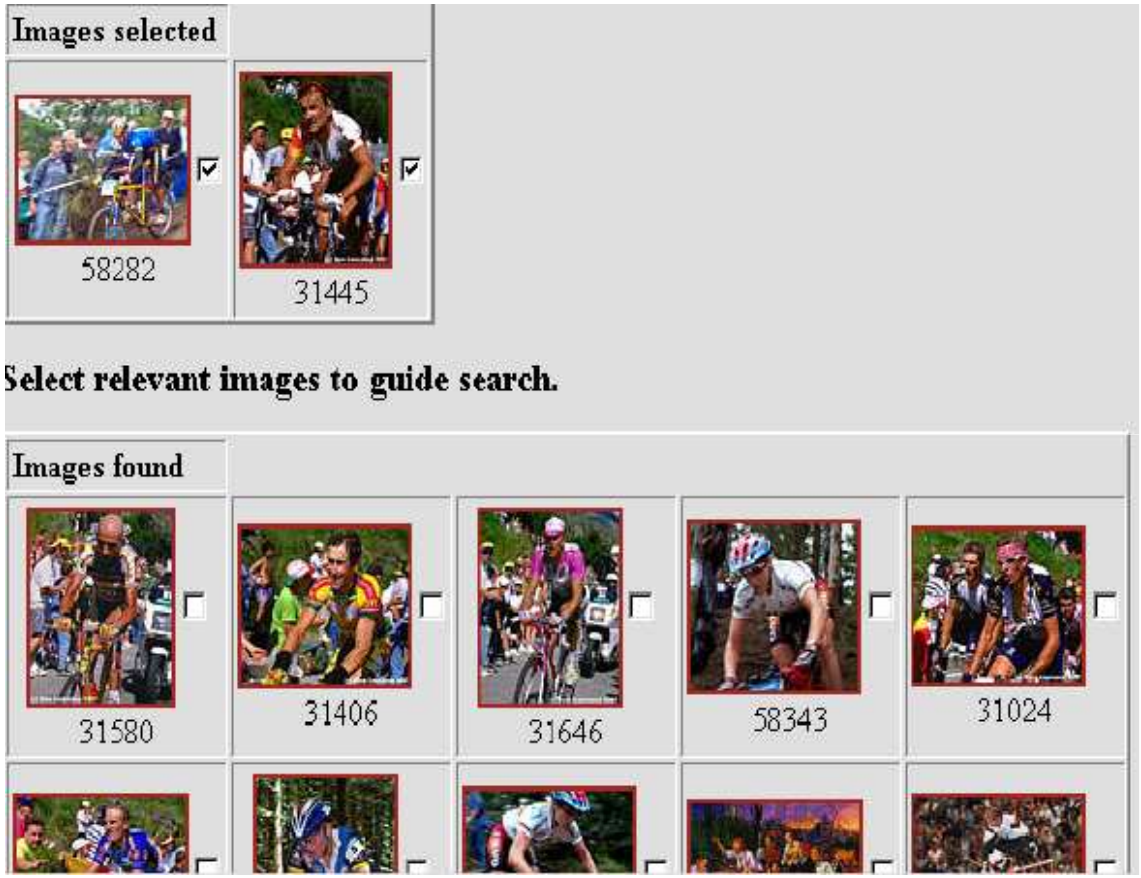
IDVL interface returned for "bin ladin" query.

The results can be tuned using many classifiers.

Relevance feedback

- In real interactive CBIR systems, the user should be allowed to interact with the system to "refine" the results of a query until he/she is satisfied.





Relevance feedback

- Example methods:
  - Query point movement
    - Query point is moved toward positive examples and moved away from negative examples.
  - Weighting features
    - The CBIR system should automatically adjust the weight that were given by the user for the relevance of previously retrieved documents.
  - Weighting similarity measures
  - Feature density estimation
  - Probabilistic relevance feedback

Relevance feedback

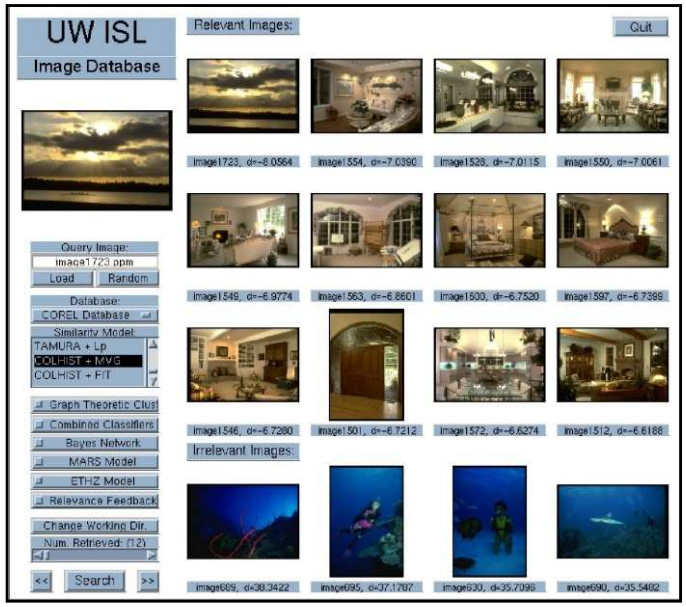
- Positive feedback

$$p(A \mid \xi_{(0)}, \xi^{+}_{(1)}, \ldots, \xi^{+}_{(n)}) \propto p(\xi^{+}_{(n)} \mid A)\, p(A \mid \xi_{(0)}, \xi^{+}_{(1)}, \ldots, \xi^{+}_{(n-1)})$$
$$p(B \mid \xi_{(0)}, \xi^{+}_{(1)}, \ldots, \xi^{+}_{(n)}) \propto p(\xi^{+}_{(n)} \mid B)\, p(B \mid \xi_{(0)}, \xi^{+}_{(1)}, \ldots, \xi^{+}_{(n-1)})$$

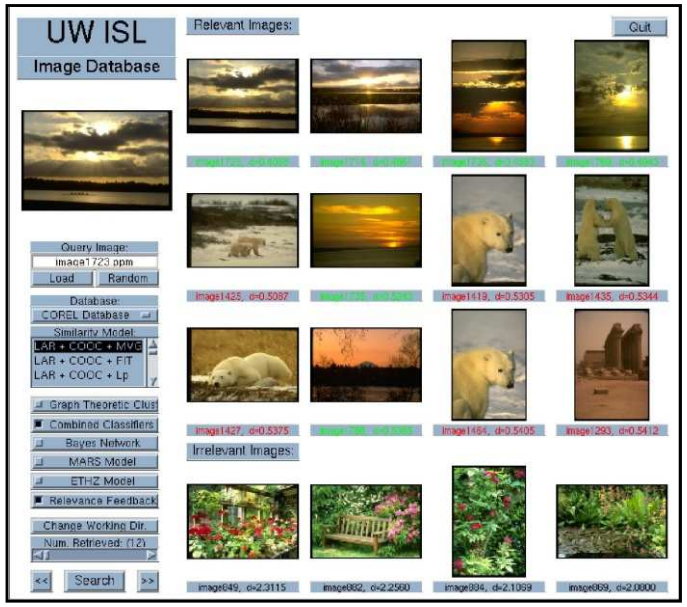
- Negative feedback

$$p(A \mid \xi_{(0)}, \xi^{+}_{(1)}, \ldots, \xi^{+}_{(n)}, \xi^{-}_{(1)}, \ldots, \xi^{-}_{(m)}) \propto$$
$$p(\xi^{-}_{(m)} \mid B)\, p(A \mid \xi_{(0)}, \xi^{+}_{(1)}, \ldots, \xi^{+}_{(n)}, \xi^{-}_{(1)}, \ldots, \xi^{-}_{(m-1)})$$
$$p(B \mid \xi_{(0)}, \xi^{+}_{(1)}, \ldots, \xi^{+}_{(n)}, \xi^{-}_{(1)}, \ldots, \xi^{-}_{(m)}) \propto$$
$$p(\xi^{-}_{(m)} \mid A)\, p(B \mid \xi_{(0)}, \xi^{+}_{(1)}, \ldots, \xi^{+}_{(n)}, \xi^{-}_{(1)}, \ldots, \xi^{-}_{(m-1)})$$

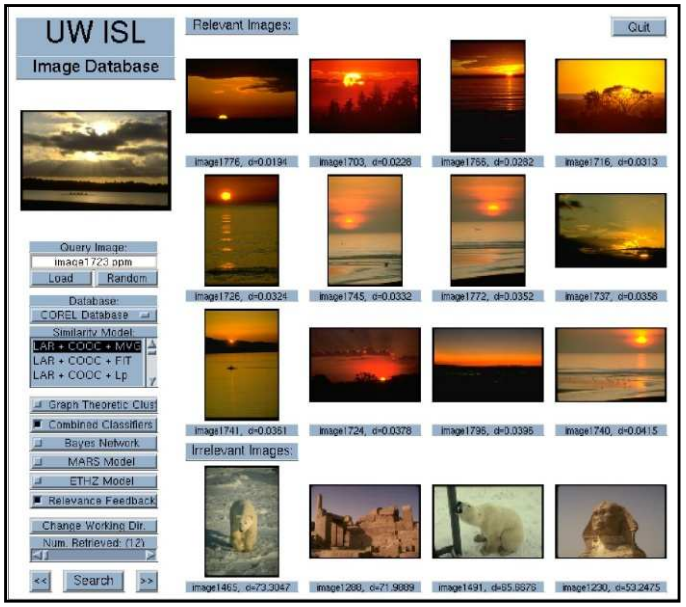
Relevance feedback



"Sunsets" using color histograms (1/12)

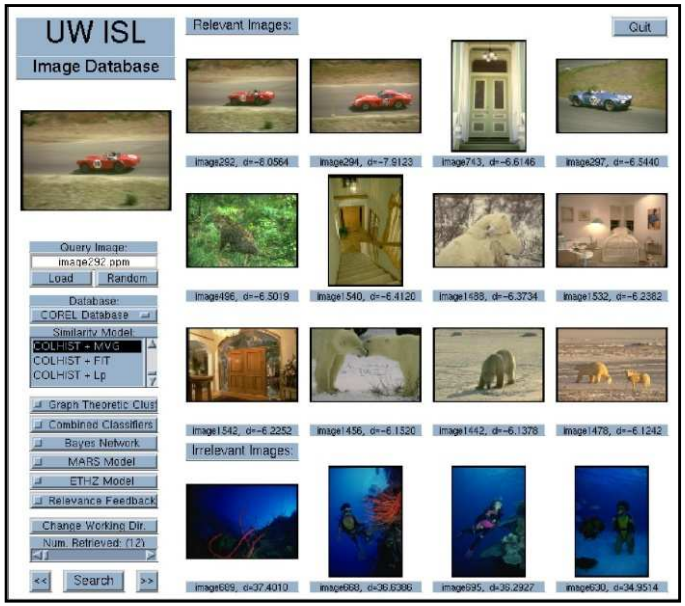


Using combined features (6/12)

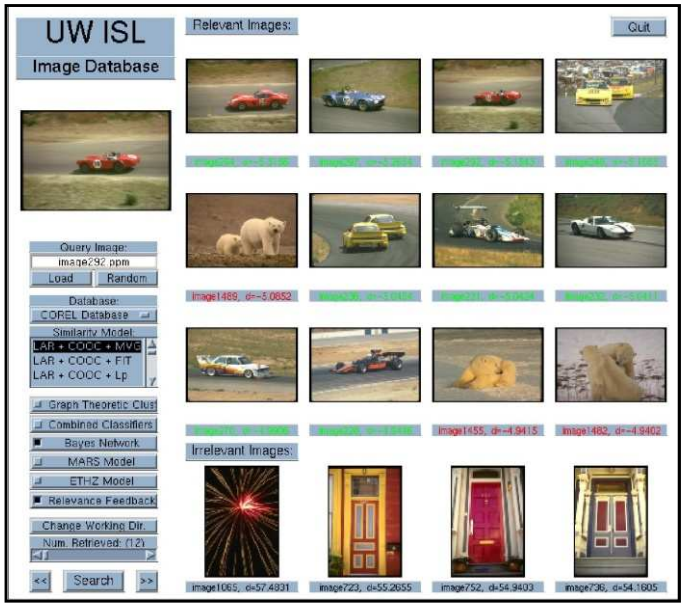


After 1st feedback (12/12)

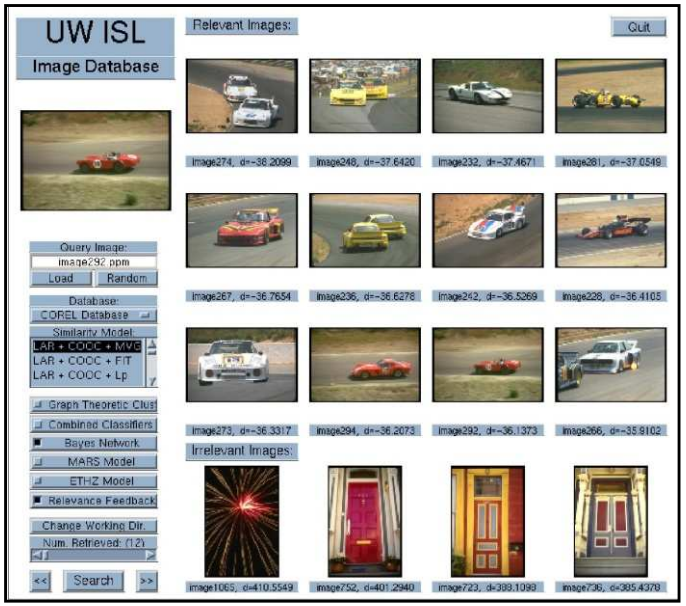
Relevance feedback



"Auto racing" using color histograms (3/12)



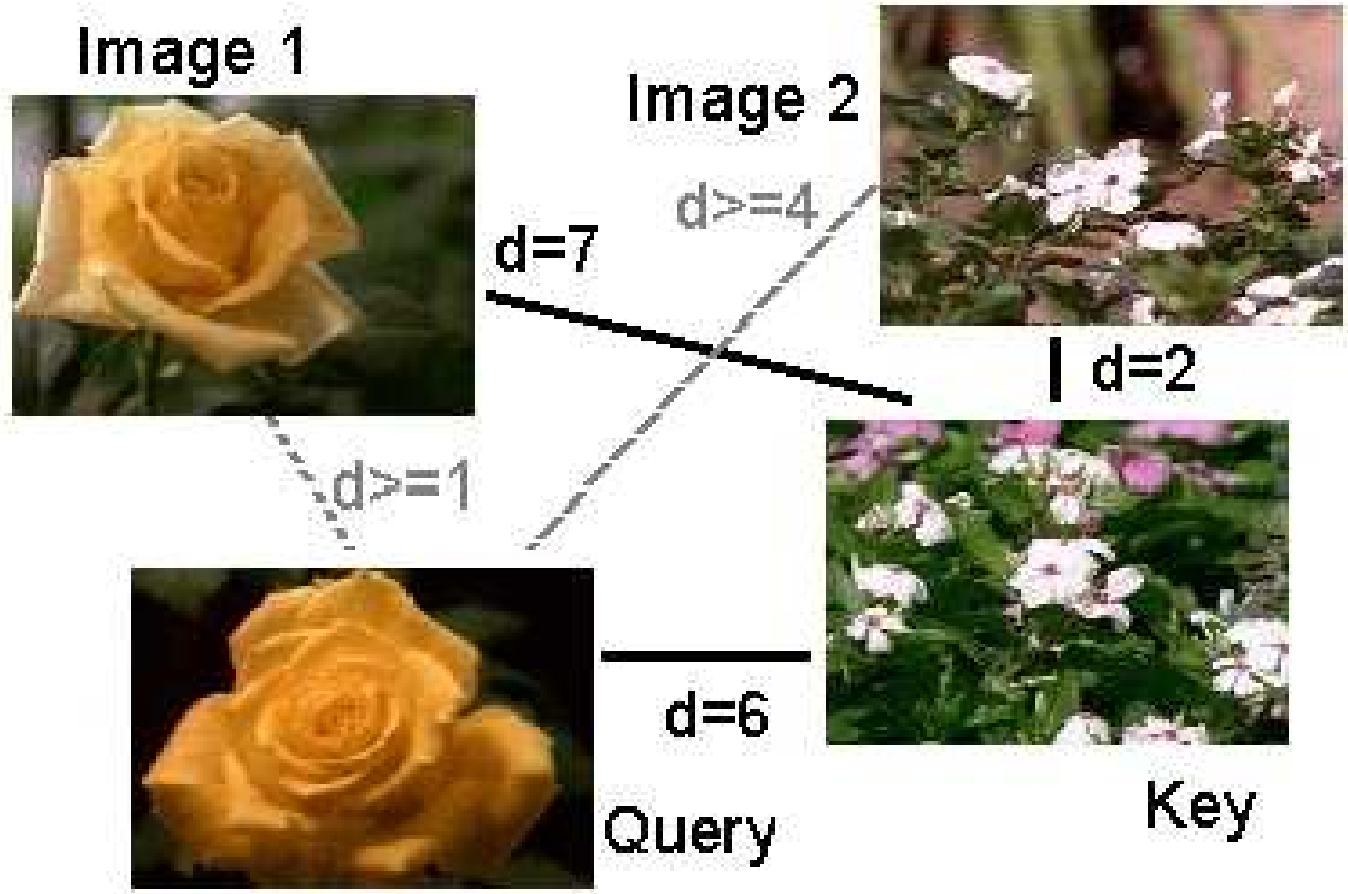
Using combined features (9/12)



After 1st feedback (12/12)

Indexing for fast retrieval

- Use of key images and the triangle inequality for efficient retrieval.



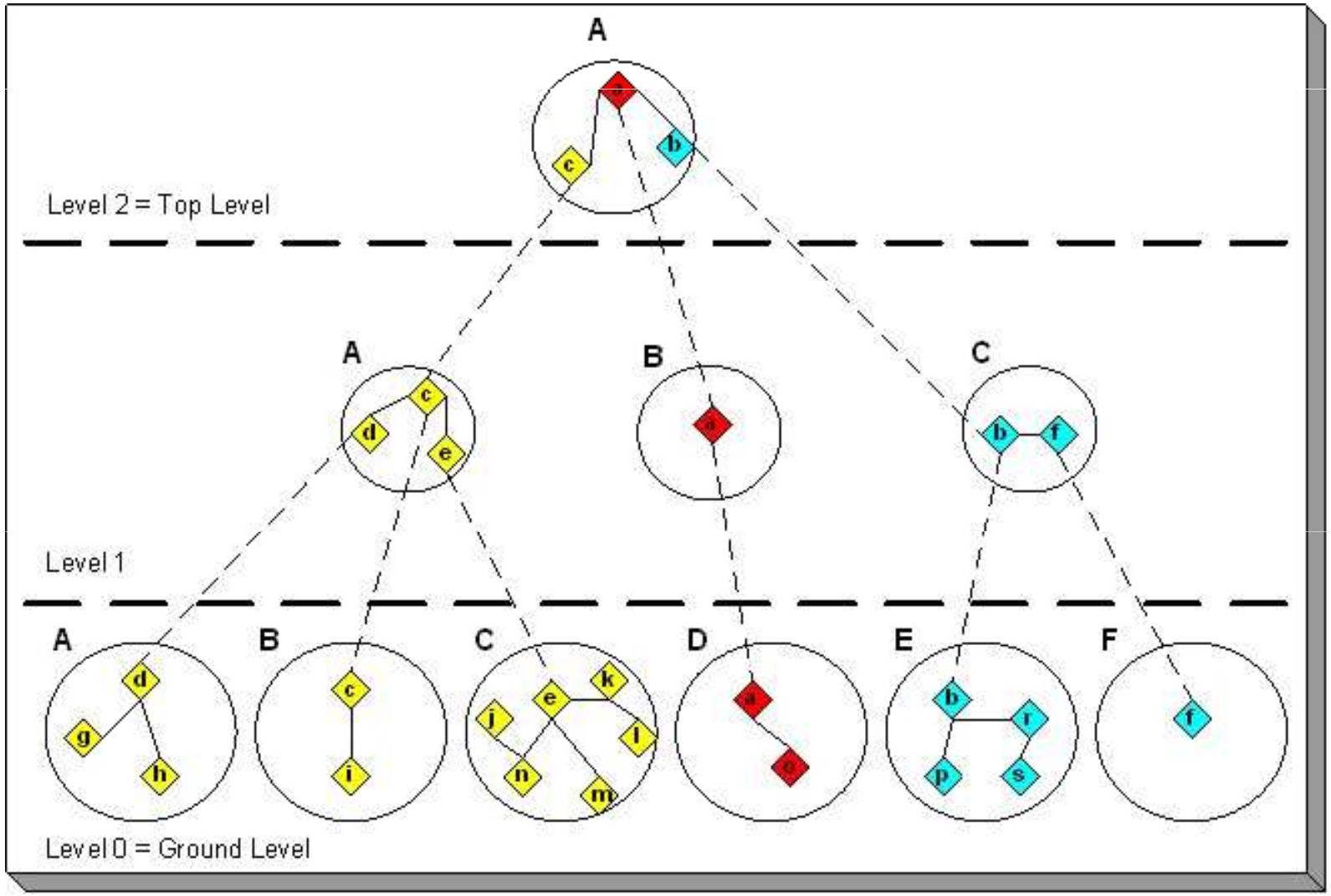
Indexing for fast retrieval

- Offline
  1. Choose a small set of key images.
  2. Store distances from database images to keys.

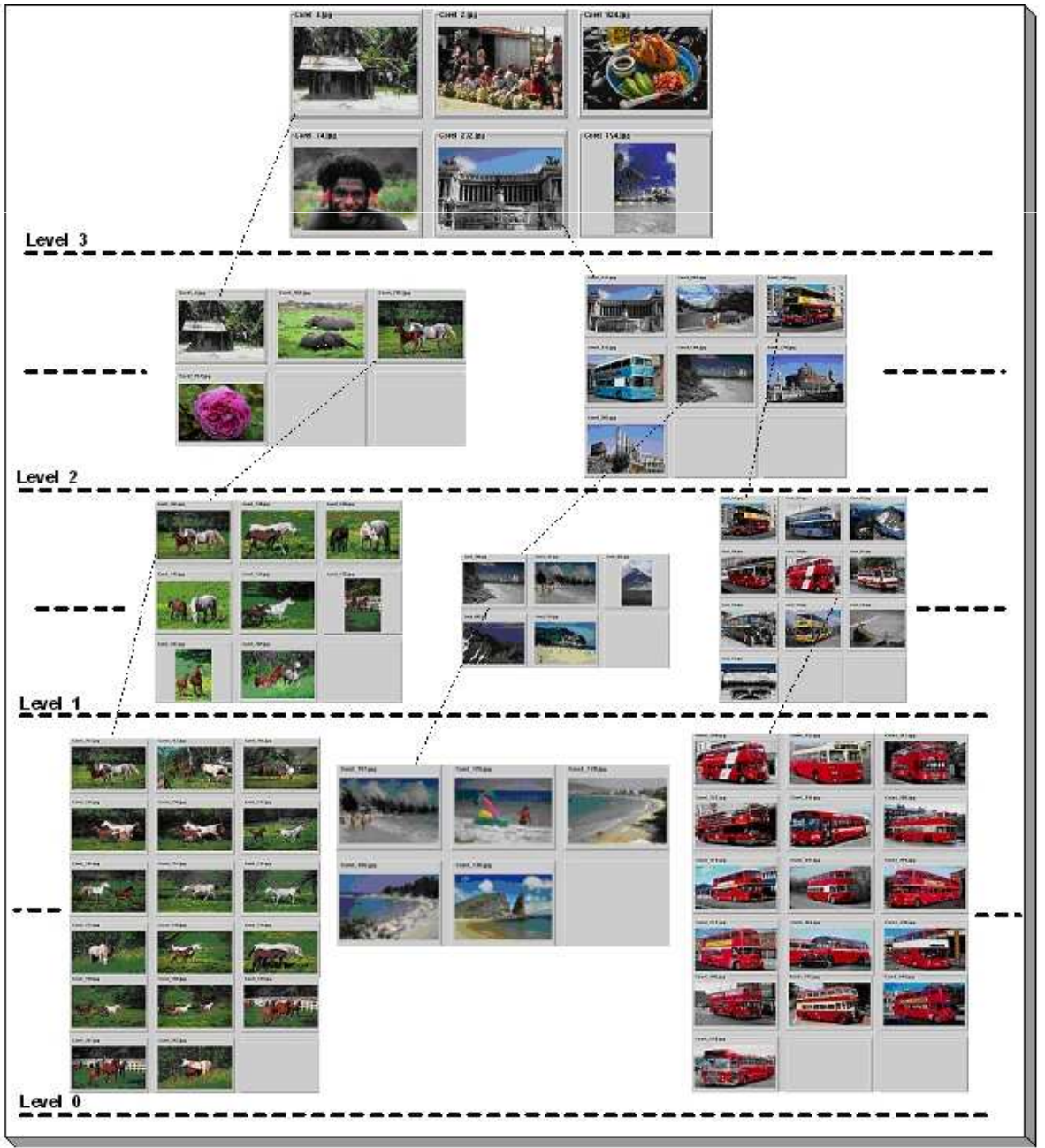
- Online (given query Q)
  1. Compute the distance from Q to each key.
  2. Obtain lower bounds on distances to database images.
  3. Threshold or return all images in order of lower bounds.

Indexing for fast retrieval

- Hierarchical cellular tree



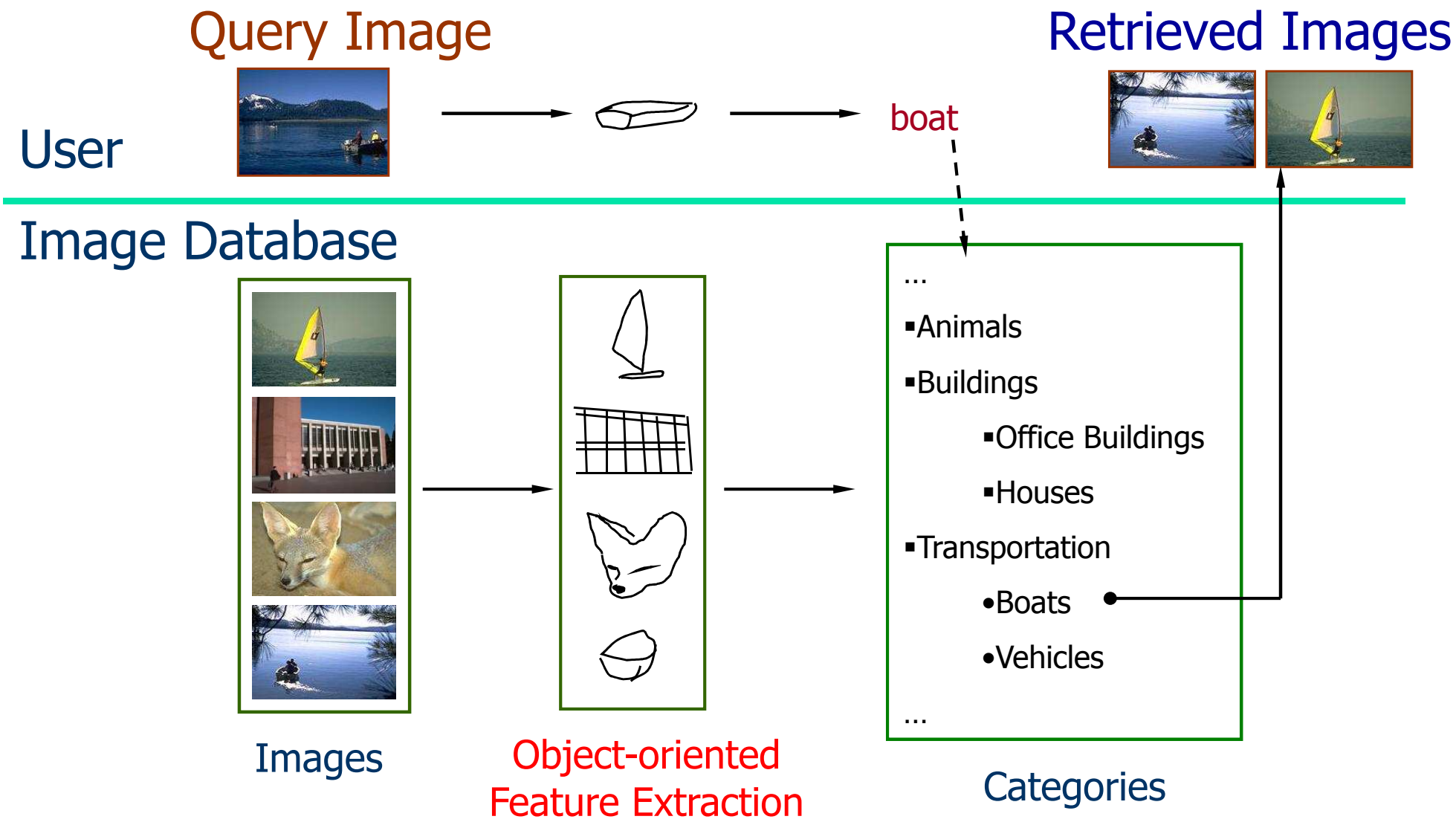
Indexing for fast retrieval



Performance evaluation

- Two traditional measures for retrieval performance in the information retrieval literature are precision and recall.
- Given a particular number of images retrieved,
  - precision is defined as the percentage of retrieved images that are actually relevant, and
  - recall is defined as the percentage of relevant images that are retrieved.

Current research objective



Demos

- Blobworld (http://elib.cs.berkeley.edu/blobworld/)
- Video Google (http://www.robots.ox.ac.uk/~vgg/research/vgoogle/index.html)
- FIDS (http://www.cs.washington.edu/research/imagedatabase/demo/fids/)
- Like Visual Shopping (http://www.like.com/)
- Google Image Search (http://images.google.com/)
- Yahoo Image Search (http://images.search.yahoo.com/)
- Flickr (http://flickr.com/)
- The ESP game (http://www.espgame.org/)

Demos

- Google Similar Images
  - http://similar-images.googlelabs.com/
- Google Image Swirl
  - http://image-swirl.googlelabs.com/
- Microsoft Bing
  - http://www.bing.com/

    First use keywords, then mouse over an image and click on show similar images