

# 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, Flickr

# Corel data set



118011  
WATER HARBOR  
SKY CLOUDS



TIGER CAT WATER GRASS



1090  
SUN CLOUDS  
WATER SKY



1015  
SUN TREE  
PLAIN SKY



143076  
MOUNTAINS TREES  
aspens VALLEY



102042  
MUSEUM memorial  
FLAGS GRASS



119094  
GARDEN BUILDING  
FLOWERS TREES

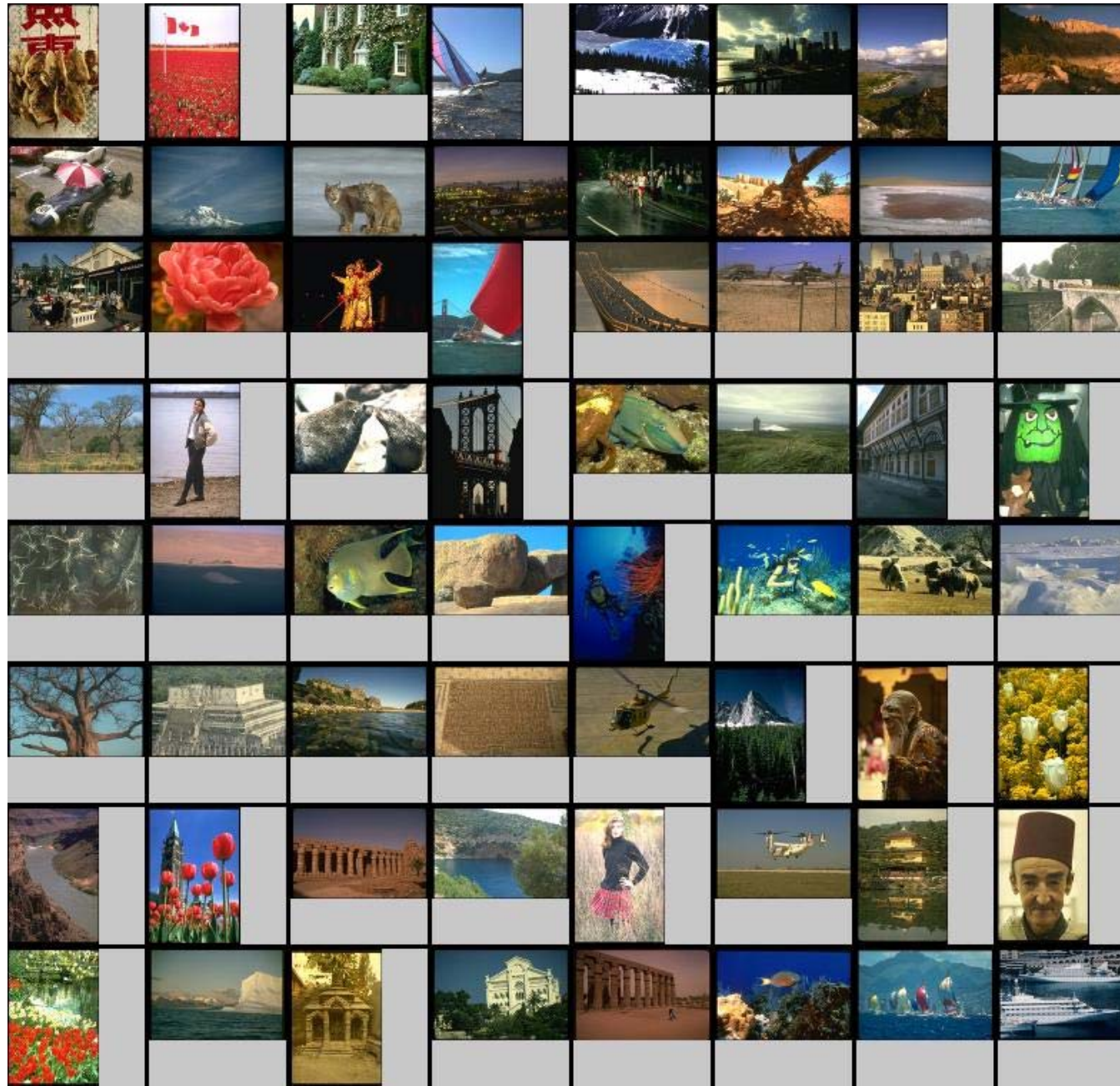


131007  
GARDEN FLOWERS  
HOUSE TREES

60,000 images with annotated keywords

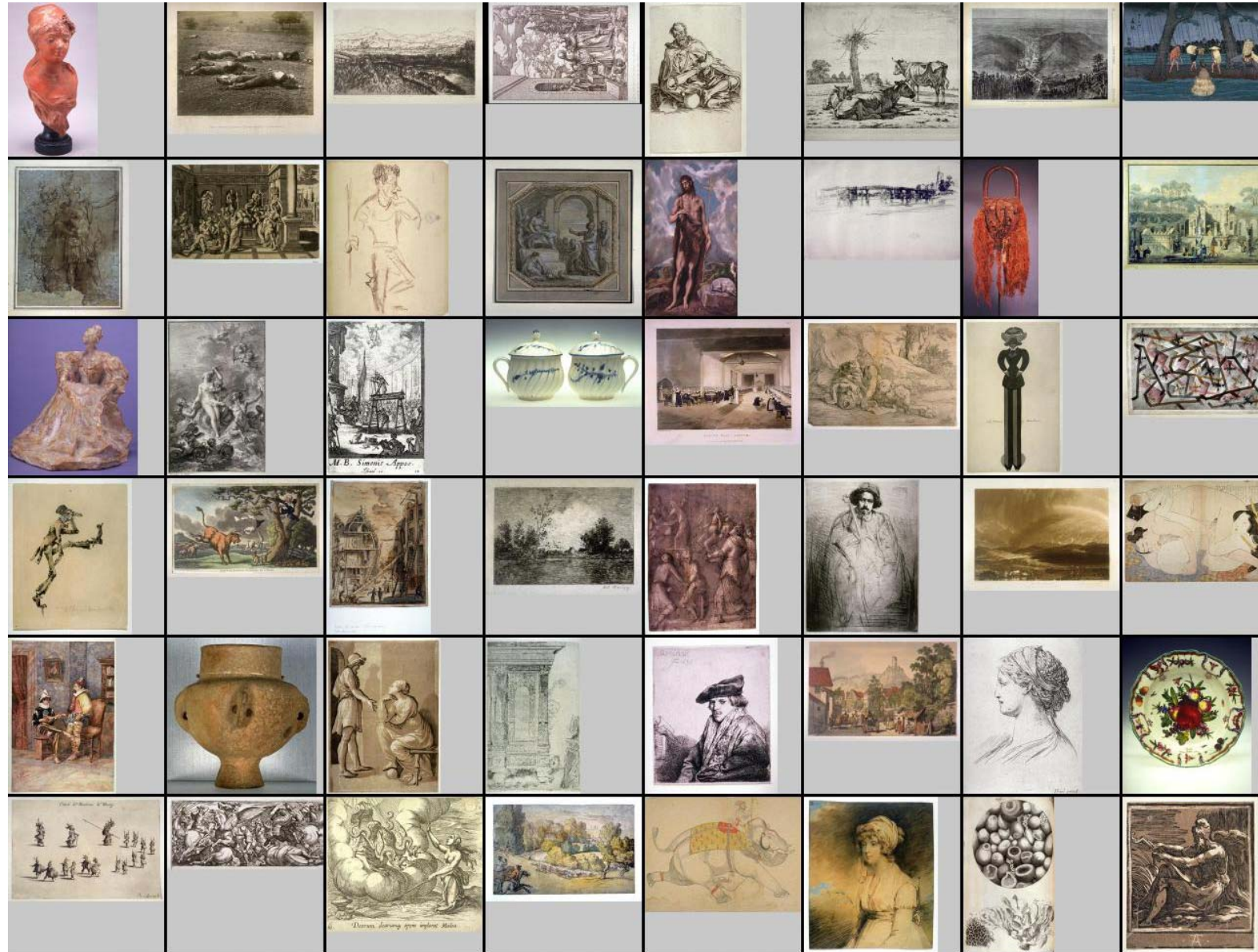


# Corel data set





# Fine Arts Museum of San Francisco



80,000 images

# Fine Arts Museum of San Francisco

---



Web number: 4359202410830012

rec number: 2

Title: Le Matin

Primary class: Print

Artist: Tissot

Description:

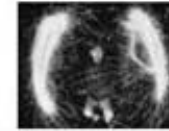
serving woman stands in a dressing room, in front of vanity with chair, mirror and mantle, holding a tray with tea and toast

Display date: 1886

Country: France

# Getty images – Hulton archive

## Hulton|Archive



With over 40 million images, this archive is an unparalleled resource of unique illustrative material, covering every facet of people's experiences and environment, recording history to the present day.

Over 600,000  
images



JD5246

### Search Hulton Archive

Search the entire online collection of over 250,000 images.

Go to Getty Images to search:

[Creative Selection >](#)

Over 35,000 Hulton Archive images available for advertising and promotional use with online purchase & download.

[Motion Archive >](#)

Historical footage from Hulton Archive.

Go to Getty Images for contemporary News & Sport imagery.



HP7110

In the News: [Cream Cone](#) [Ernst Haas: A Pioneer In Colour](#)

[What's New](#)

[About Hulton|Archive](#)

[Contact Us](#)



# 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](http://gardening.about.com)  
[ [More from z.about.com](http://More from z.about.com) ]



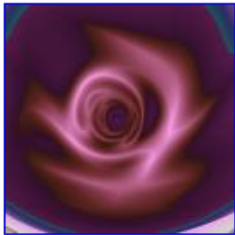
Welcome to the Corpus Christi **Rose**  
...  
351 x 334 - 51k - gif  
[www.geocities.com](http://www.geocities.com)



**Frosty Rose**  
600 x 451 - 70k - jpg  
[blogs.warwick.ac.uk](http://blogs.warwick.ac.uk)



Dominic Cavendish reviews The **Rose** We've been in the business of **rose** .  
...  
400 x 313 - 40k - jpg  
[www.telegraph.co.uk](http://www.telegraph.co.uk)



**Rose**  
512 x 512 - 19k - jpg  
[www.parabola.me.uk](http://www.parabola.me.uk)



**ROSE Online**  
800 x 640 - 393k - jpg  
[www.gameogre.com](http://www.gameogre.com)



Tracey **Rose** The Thinker, 1996  
500 x 451 - 26k - jpg  
[www.artthrob.co.za](http://www.artthrob.co.za)



Tracey **Rose** Span II, 1997  
317 x 500 - 18k - jpg  
[www.artthrob.co.za](http://www.artthrob.co.za)



The **rose** apple is occasionally ...  
350 x 307 - 57k - jpg  
[www.tradewindsfruit.com](http://www.tradewindsfruit.com)



Lewis **Rose** also known as Lewis N. ... **Rose** Parade Seating Chart Seating ... **Rose** Quartz point shape in Sterling ...  
347 x 348 - 18k - jpg  
[lewisrose.com](http://lewisrose.com)



**Rose** Quartz point shape in Sterling ...  
449 x 354 - 18k - gif  
[www.barrystickets.com](http://www.barrystickets.com)



**Rose** Quartz point shape in Sterling ...  
456 x 478 - 15k - jpg  
[www.wehug.com](http://www.wehug.com)



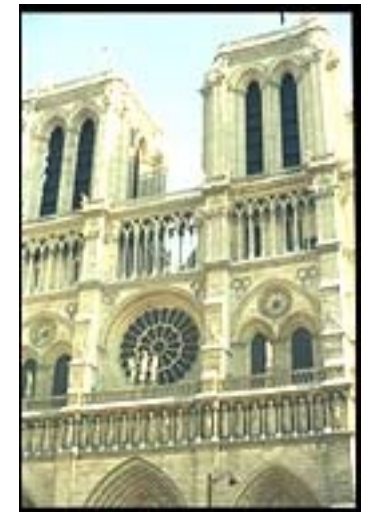
The Exorcism of Emily **Rose**  
300 x 375 - 29k  
[www.smh.com.au](http://www.smh.com.au)



**rose rose** 6499 hits  
574 x 576 - 33k - jpeg  
[www.firstmonday.org](http://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.Flavols

Price Image  
Lightbox Cart



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

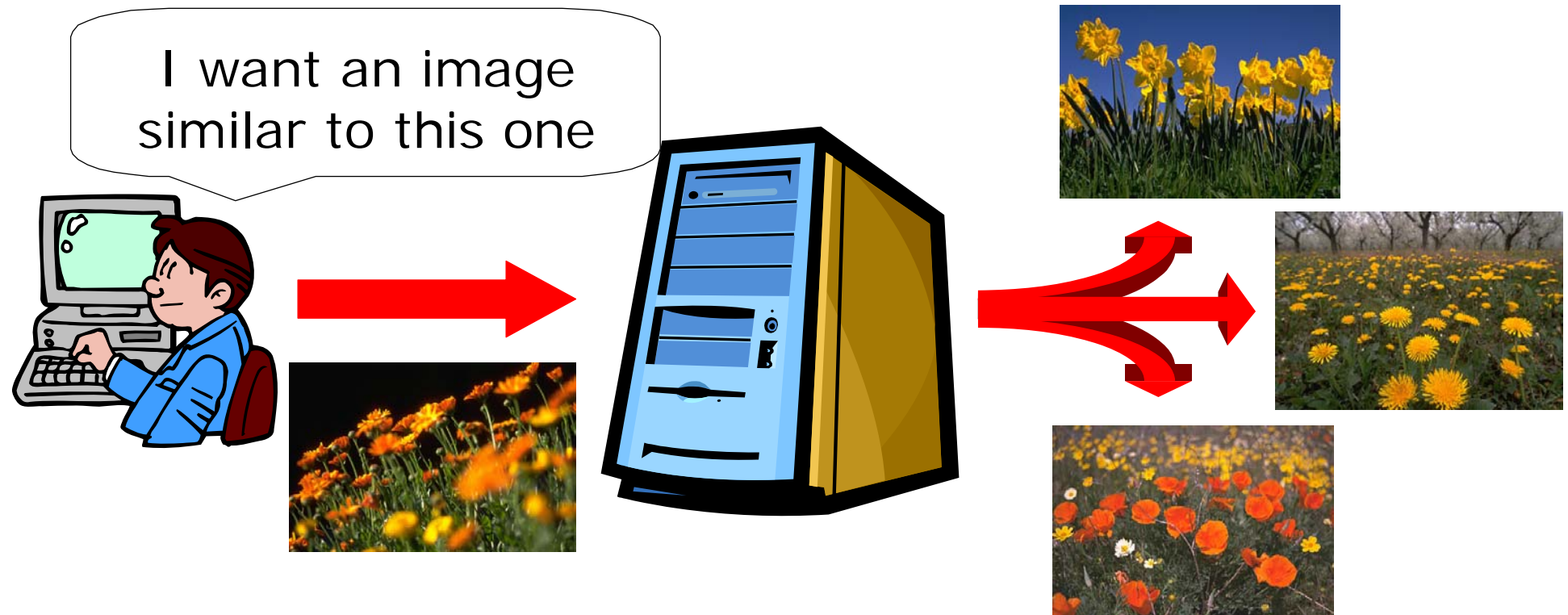
Price Image

# Difficulties with keywords

---

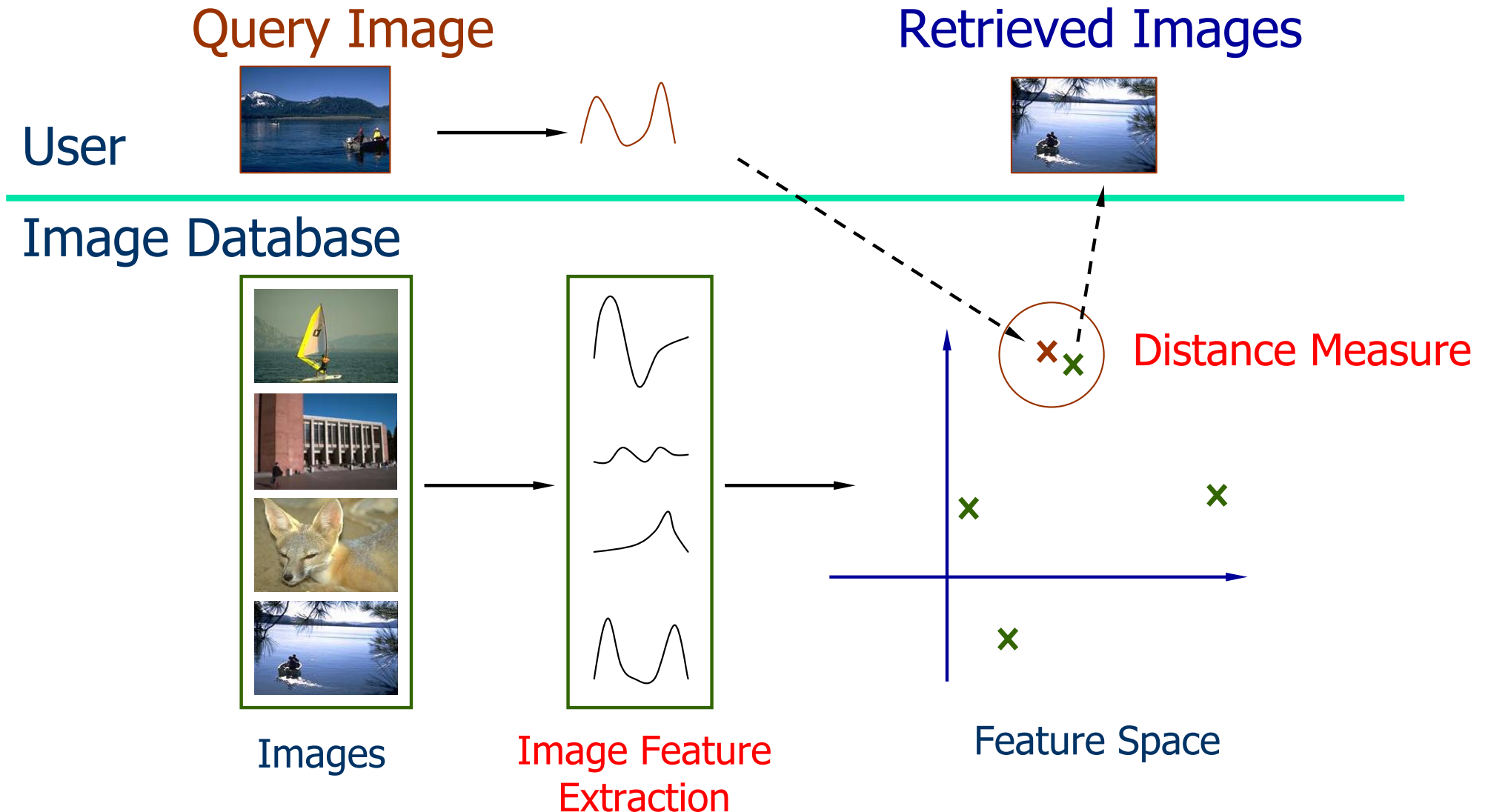
- Images may not have keywords.
    - (An image is worth ... how many key-words?)
  - Query is not easily satisfied by keywords.
    - “A casually dressed couple gazing into each others eyes lovingly with dramatic clouds in the background.”
    - “Pretty girl doing something active, sporty in a summery 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



Category search using query by example

# Content-based image retrieval



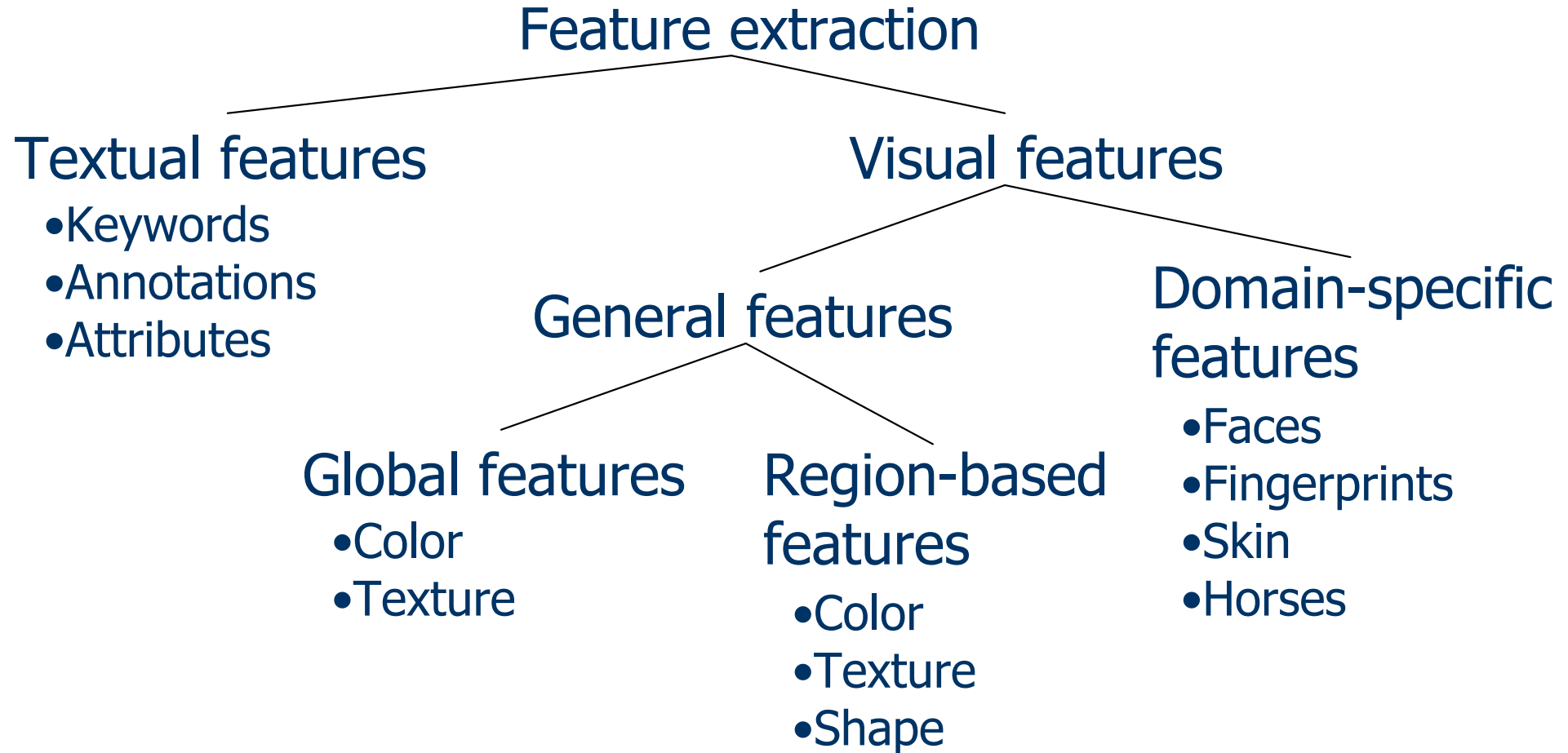
# Image representations and features

---

- 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 representations and features

---





# Image similarity

---

- Distance measures:
  - Euclidean distance
  - Other  $L_p$  metrics
  - Histogram intersection
  - Cosine distance
  - Earth mover's distance
- Probabilistic similarity measures:
  - $P(\text{relevance} \mid \text{two images})$
  - $P(\text{relevance} \mid \text{two images}) / P(\text{irrelevance} \mid \text{two images})$

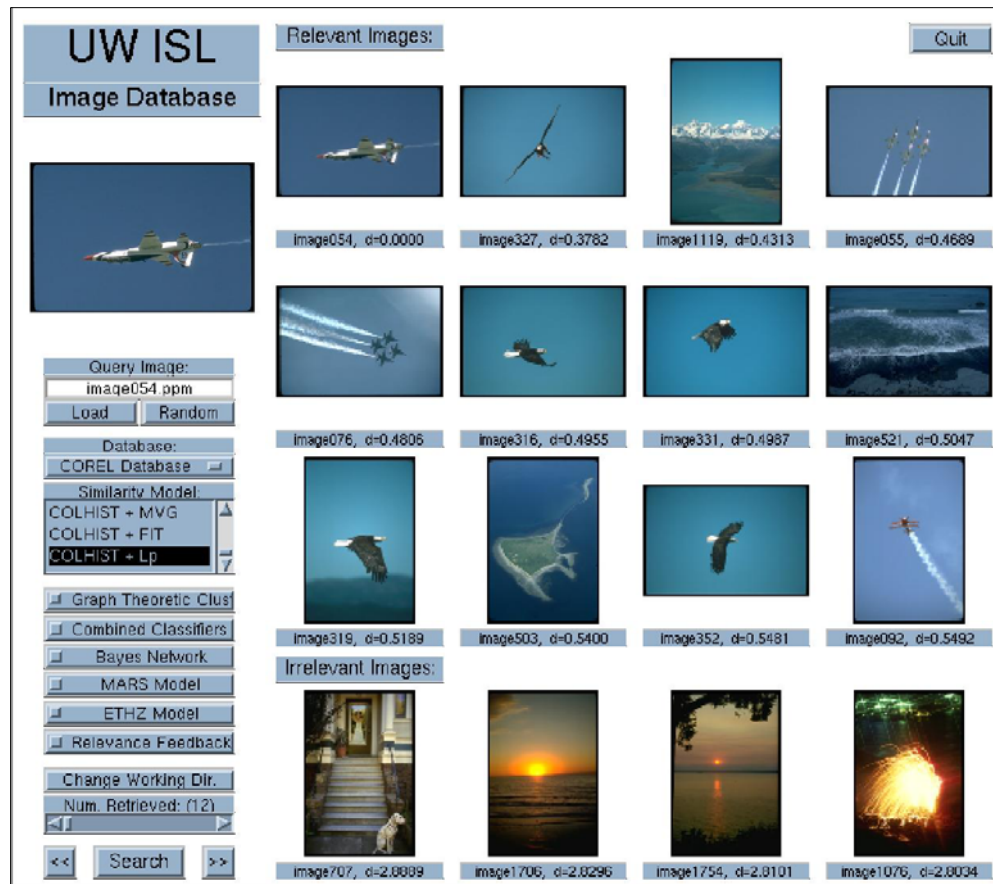


# Global histograms

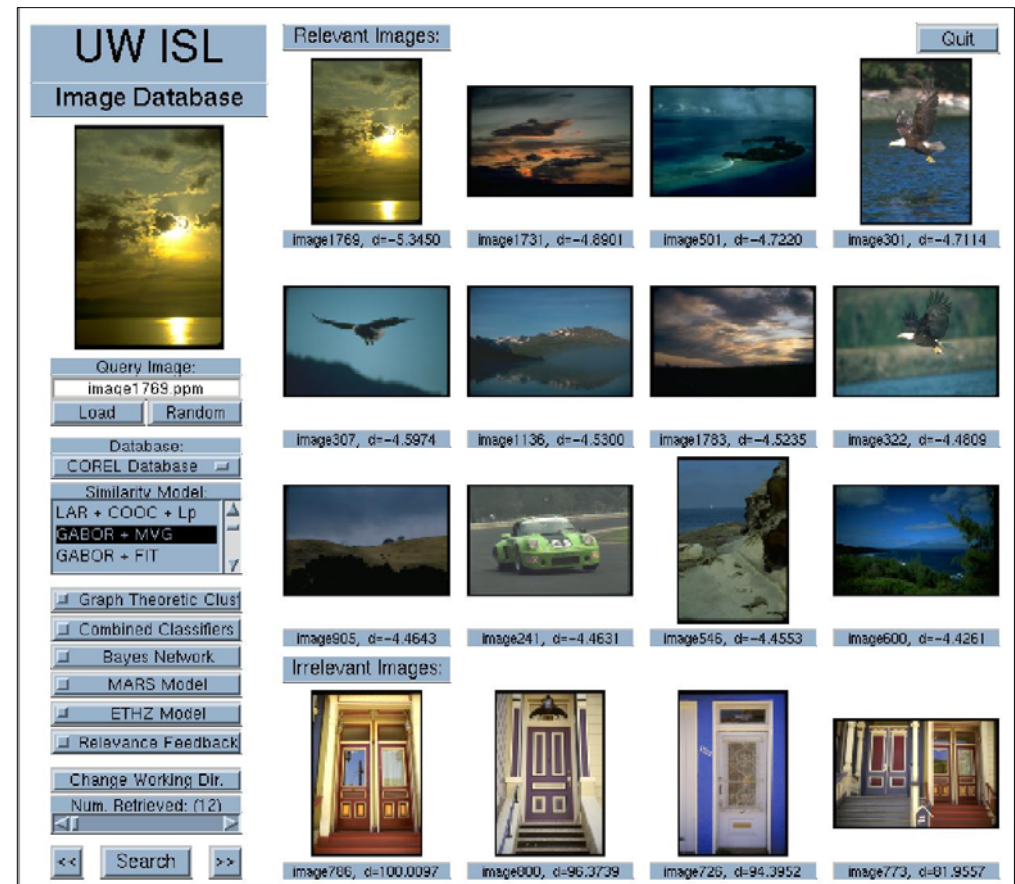
- Searching using global color histograms



# Global histograms

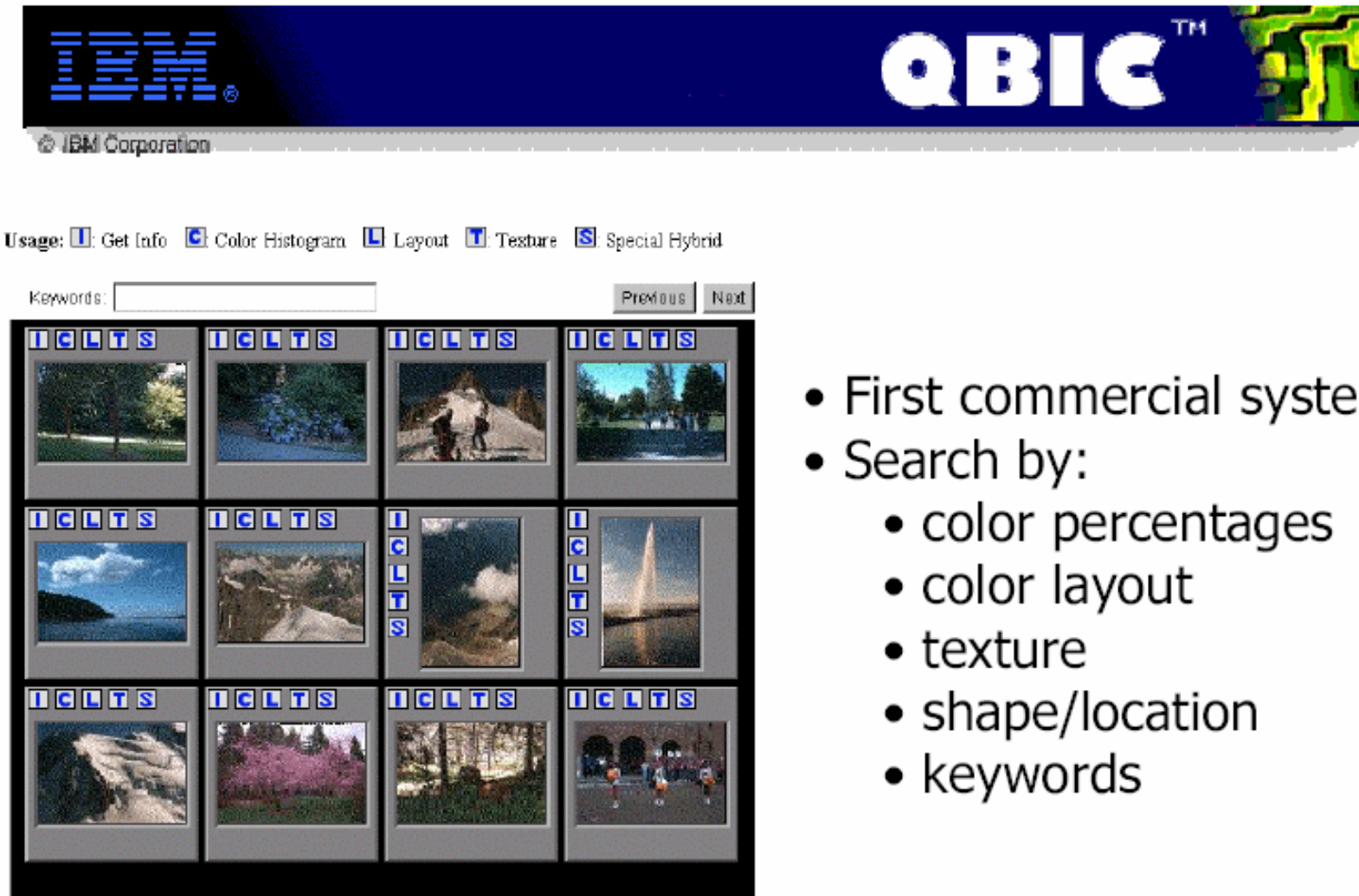


"Airplanes" using color histograms (4/12)



"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://www.qbic.almaden.ibm.com>

# Color histograms in QBIC

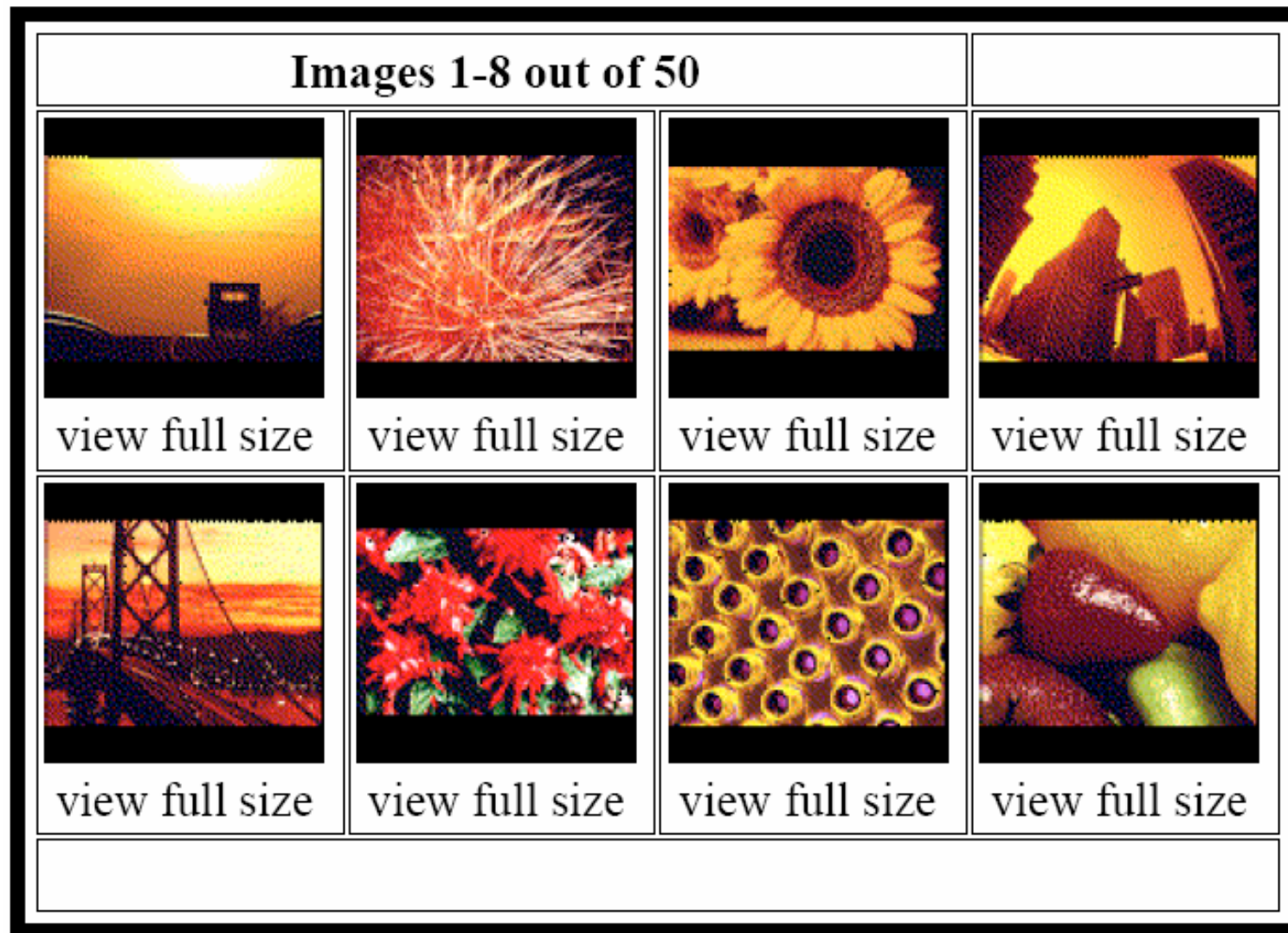
- The QBIC color histogram distance is:  
$$d_{\text{hist}}(I, Q) = (h(I) - h(Q))^T A (h(I) - h(Q)).$$
- $h(I)$  is a K-bin histogram of a database image.
- $h(Q)$  is a K-bin histogram of the query image.
- $A$  is a K x K similarity matrix.

	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?


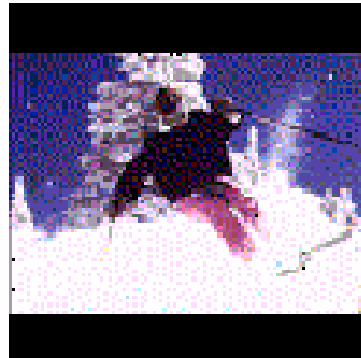
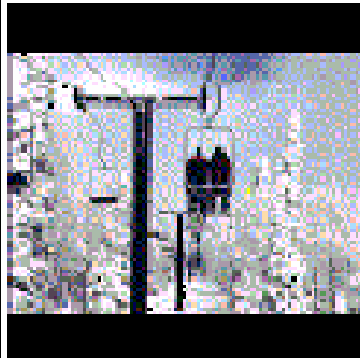

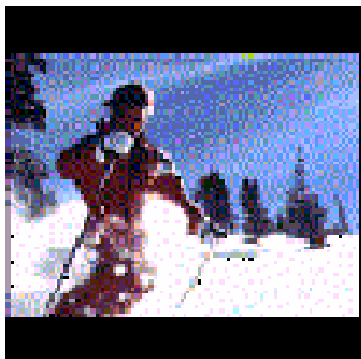
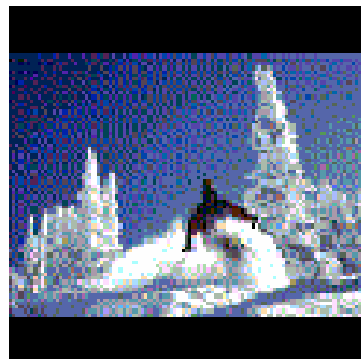
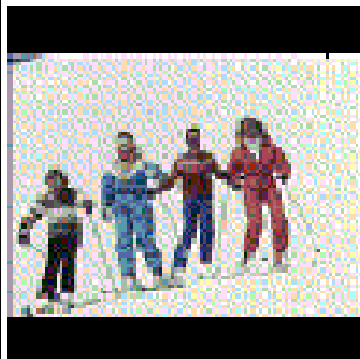



# Color percentages in QBIC



%40 red, %30 yellow, %10 black

# Color layout in QBIC

Images 1-8 out of 41				
				
view full size	view full size	view full size	view full size	
				
view full size	view full size	view full size	view full size	
Columns: Rows:				

# 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

---

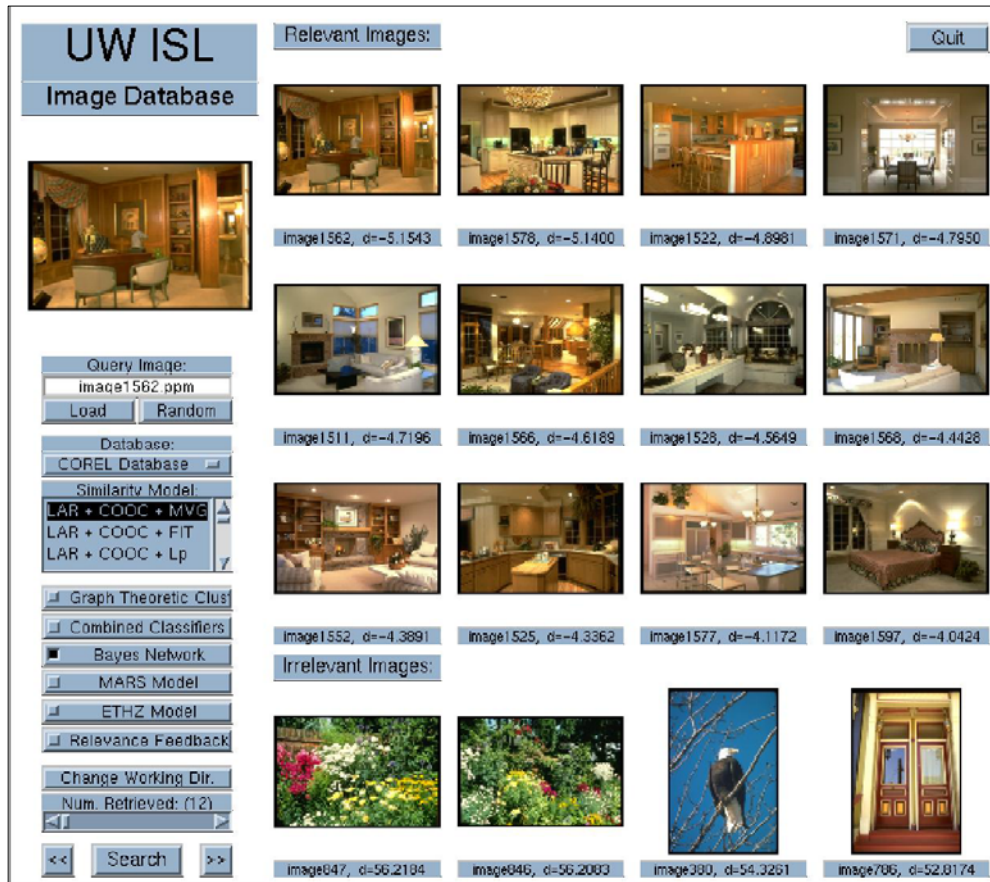
- Two classes:
  - Relevance class A
  - Irrelevance class B
- Bayes classifier
  - Assign  $(\xi_i, \xi_j)$  to  $\begin{cases} A & \text{if } P(A | (\xi_i, \xi_j)) > P(B | (\xi_i, \xi_j)) \\ B & \text{otherwise} \end{cases}$

- Discriminant function for classification

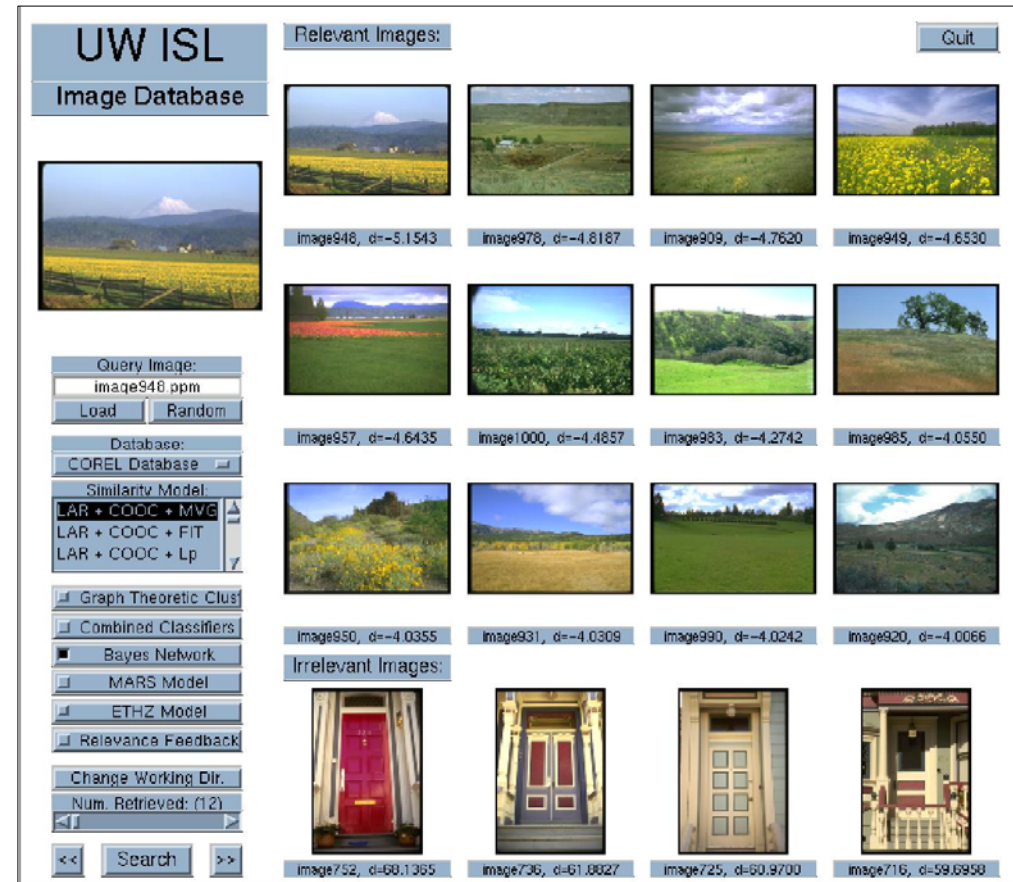
$$\Delta(\xi_i, \xi_j) = \frac{P(A | (\xi_i, \xi_j))}{P(B | (\xi_i, \xi_j))} = \frac{P((\xi_i, \xi_j) | A) P(A)}{P((\xi_i, \xi_j) | B) P(B)}$$

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

# Probabilistic similarity measures



"Residential interiors" (12/12)

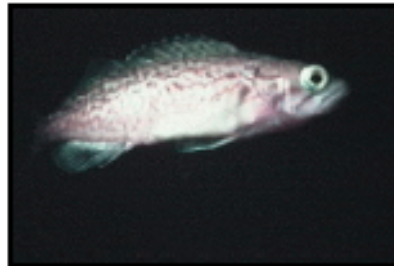
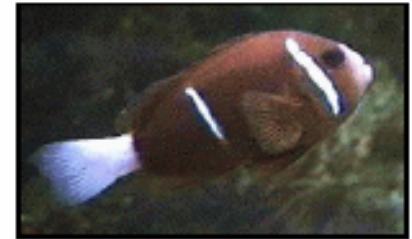


"Fields" (12/12)

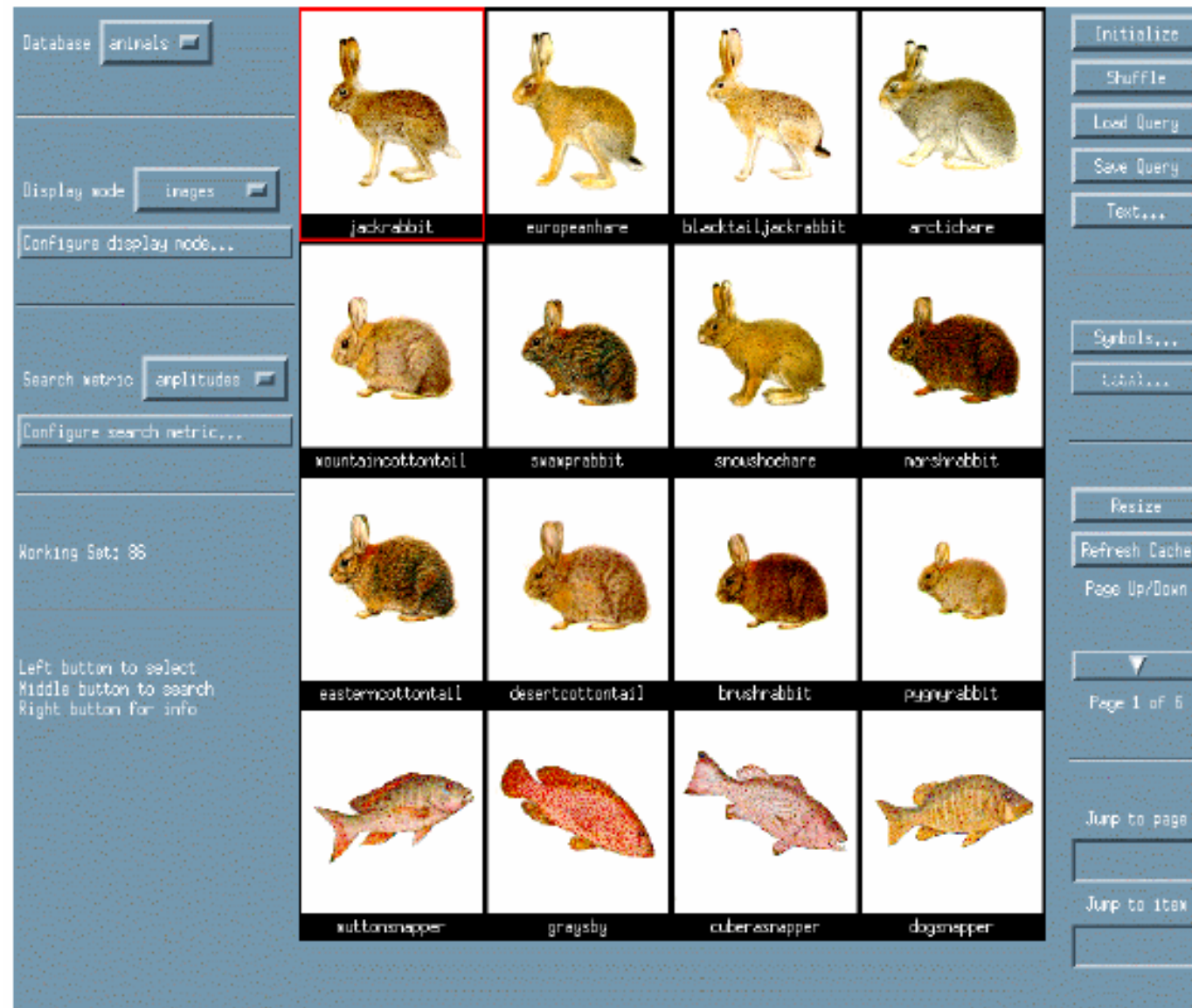


# Shape-based retrieval

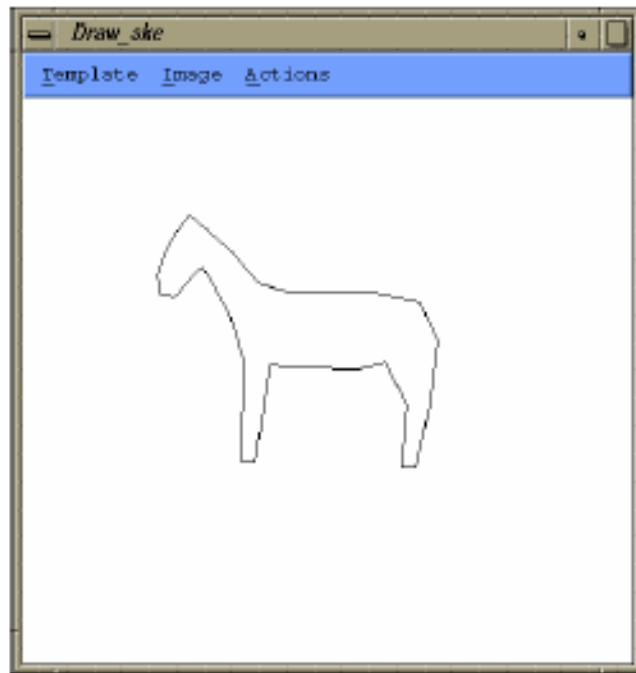
Find more shapes like this



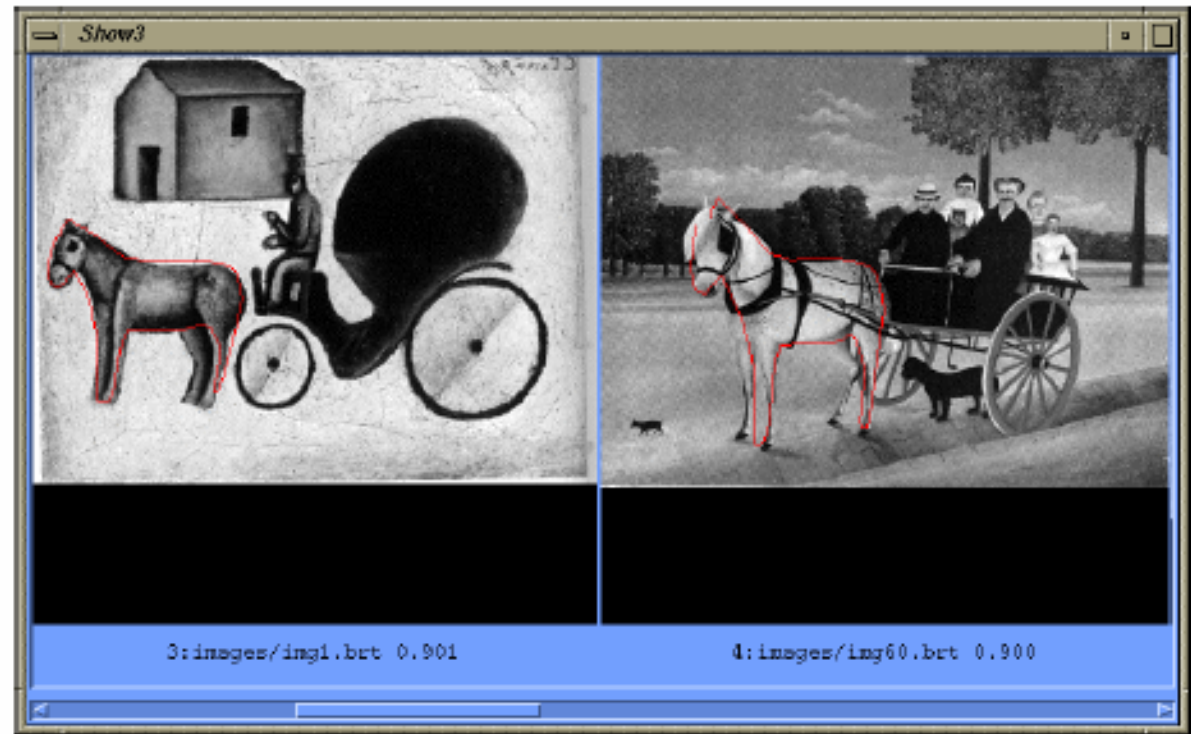
# Shape-based retrieval



# 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.



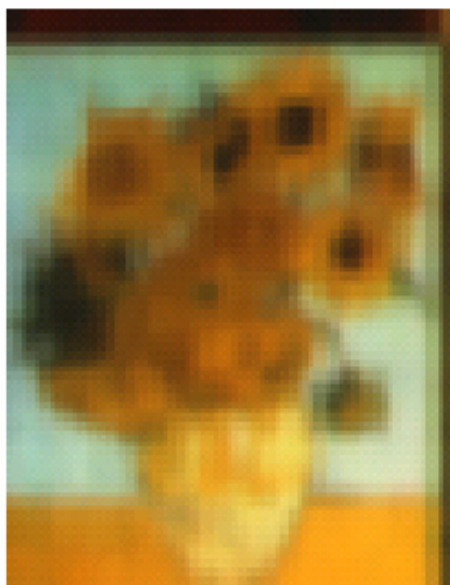
# Iconic matching

- Wavelet-based image compression
- Quantization of coefficients

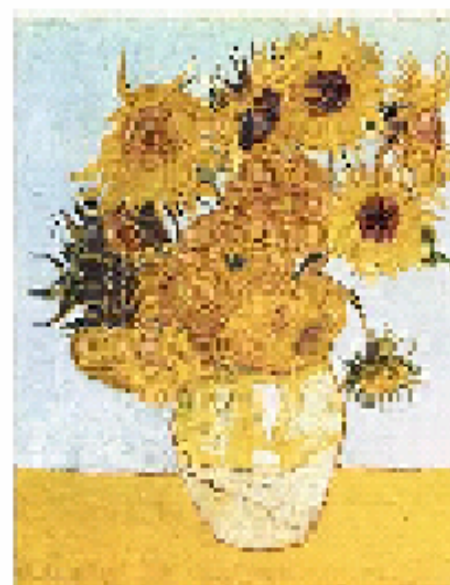
painted



scanned



target



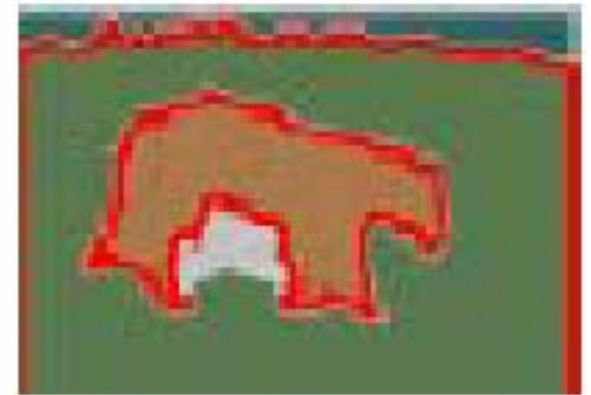
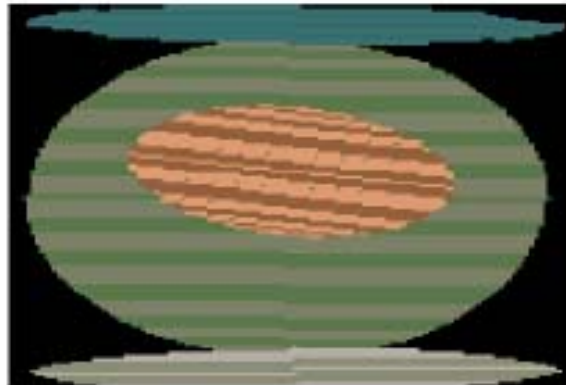
From Jacobs, Finkelstein, & Salesin  
*Fast Multi-Resolution Image Querying, SIGGRAPH 1995*

# 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

Query image: 108019      Query blobs

Querying from 10000 images (full search).

blob and feature importance:					
	blob (overall)	color	texture	location	shape
blob 2	very	very	somewhat	not	not
blob 1	somewhat	very	somewhat	not	not

1: 108084 (score = 0.9811)      New query

2: 108029 (score = 0.98286)      New query

3: 108024 (score = 0.98115)      New query

4: 108056 (score = 0.97944)      New query

5: 108044 (score = 0.97944)      New query

6: 108051 (score = 0.97944)      New query

7: 108004 (score = 0.9774)      New query

8: 238042 (score = 0.97039)      New query

Query image: 108019      Query blobs

Querying from 10000 images (full search).

blob and feature importance:					
	blob (overall)	color	texture	location	shape
blob 2	somewhat	very	somewhat	not	not
background	very	very	not	not	not

1: 108074 (score = 0.98705)      New query

2: 108064 (score = 0.97694)      New query

3: 384098 (score = 0.97442)      New query

4: 384021 (score = 0.97296)      New query

5: 108072 (score = 0.97028)      New query

6: 172036 (score = 0.96641)      New query

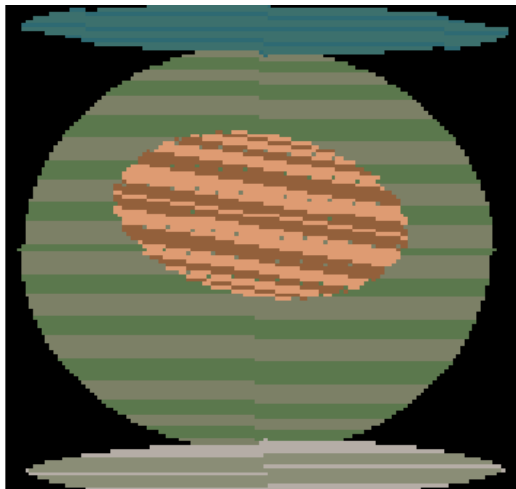
7: 384080 (score = 0.95897)      New query



# Retrieval using spatial relationships

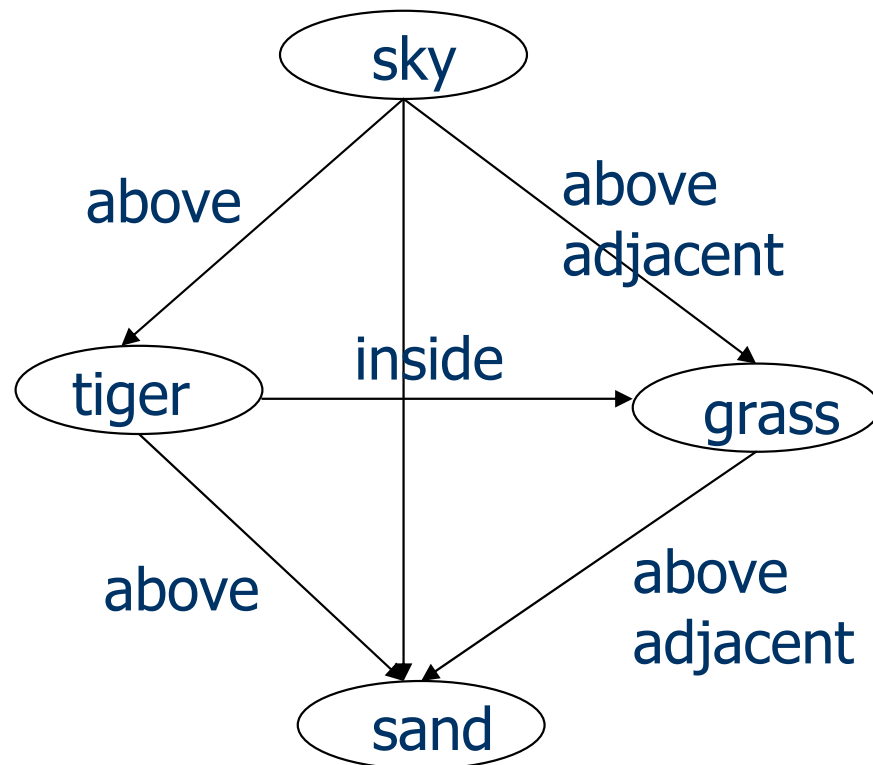


image



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

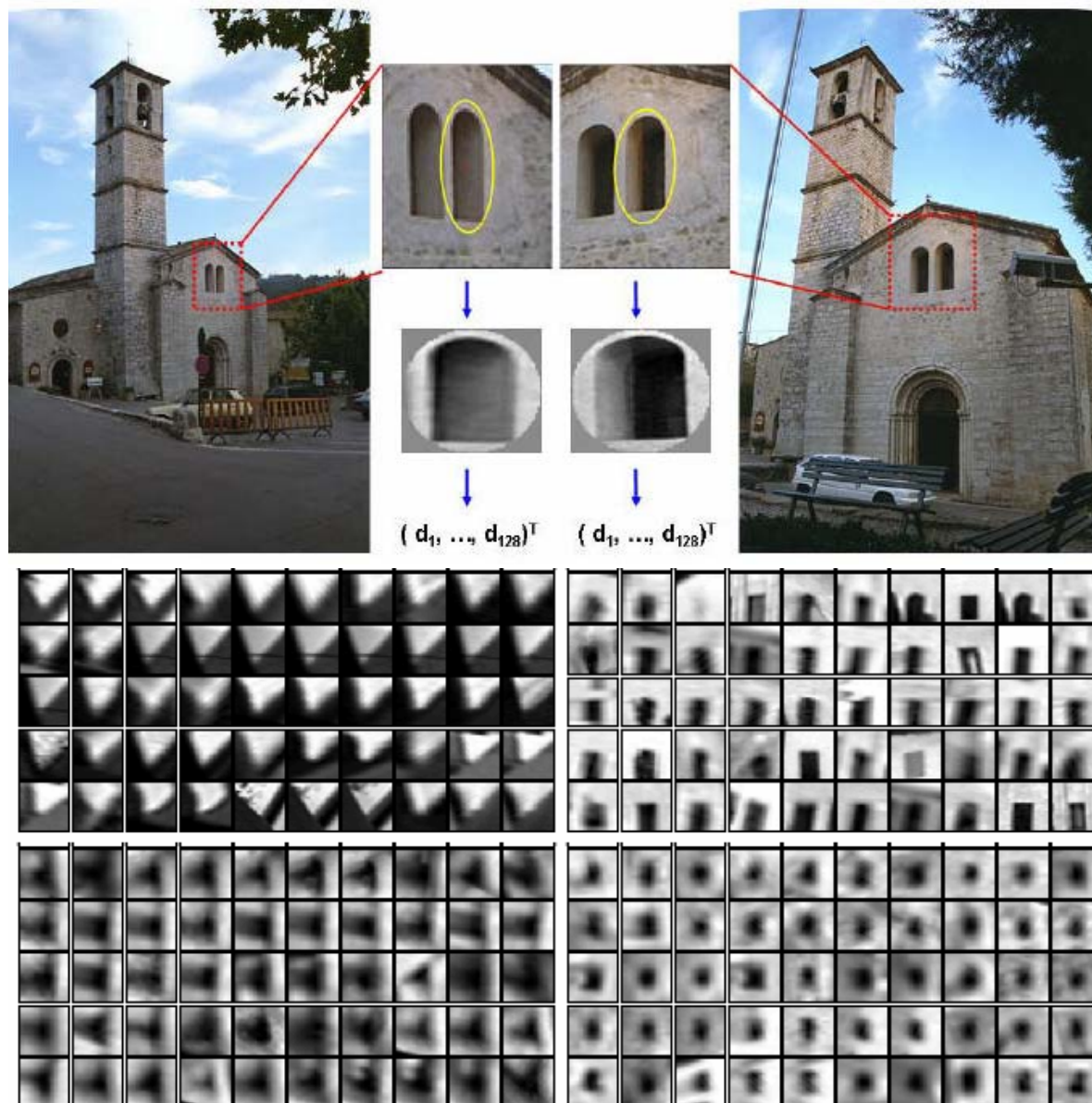




# Video Google: object matching



# 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.

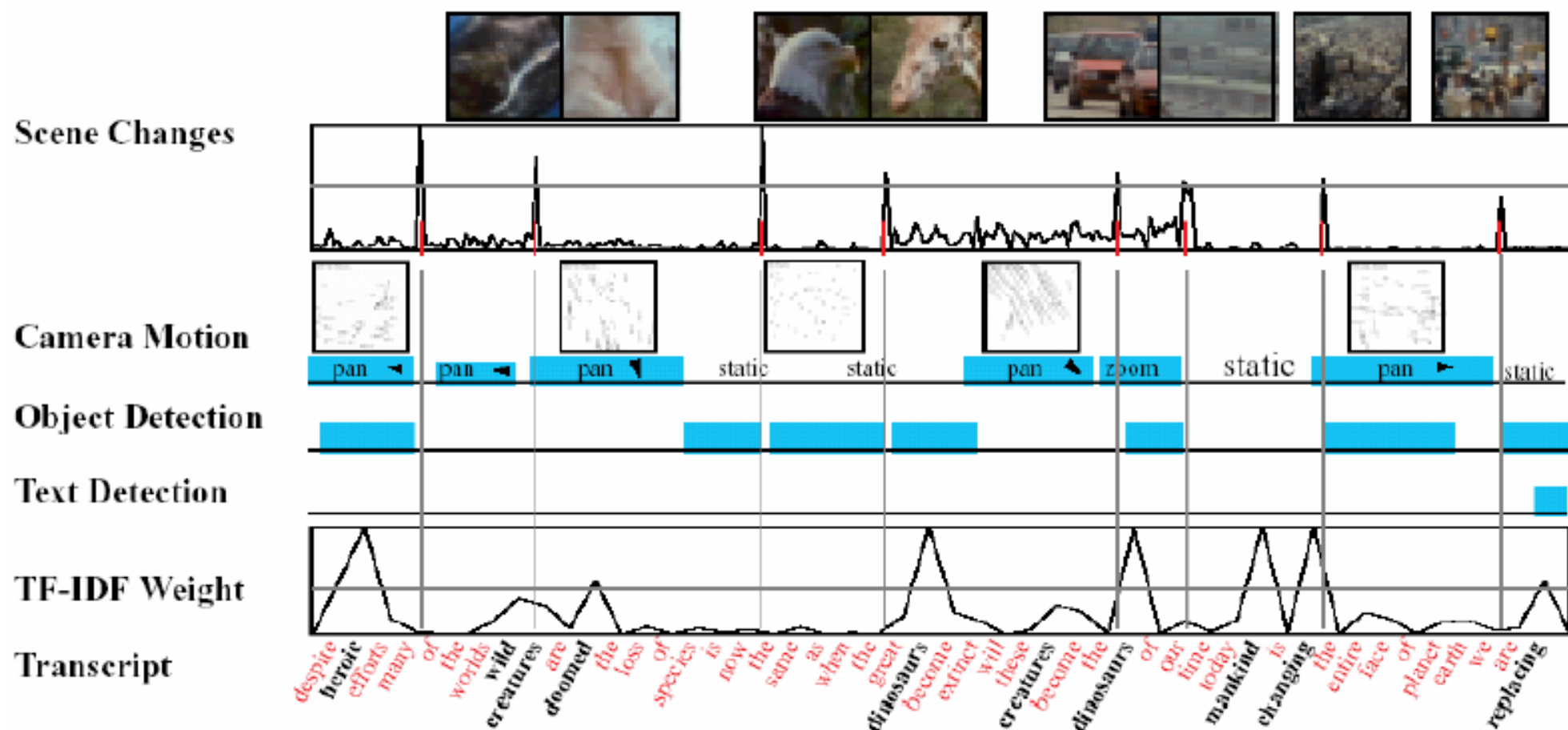
## Document 2

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





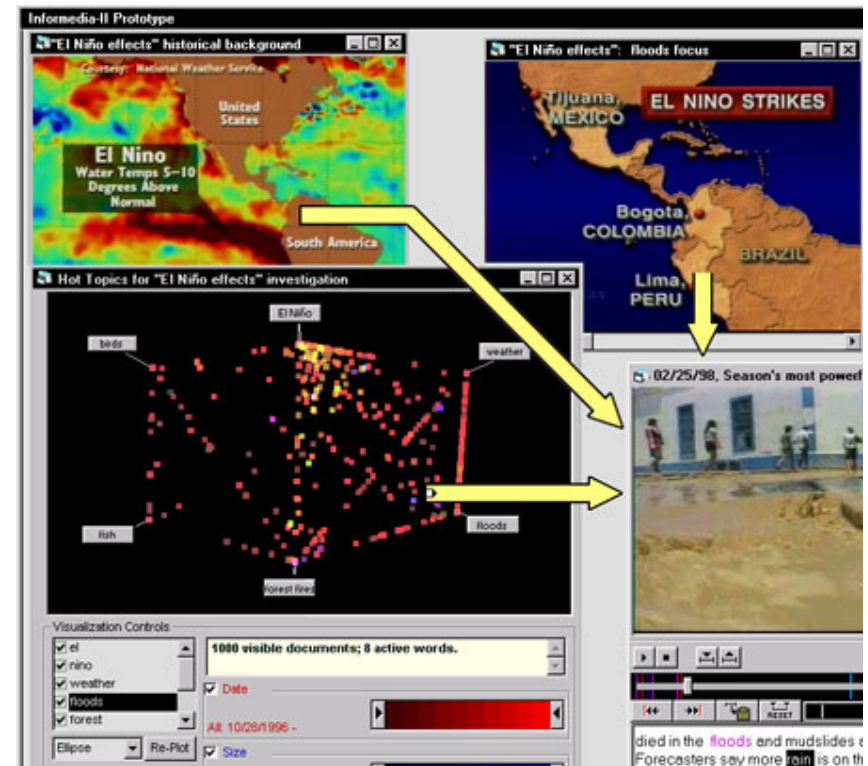
# Event detection, indexing, retrieval

---

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



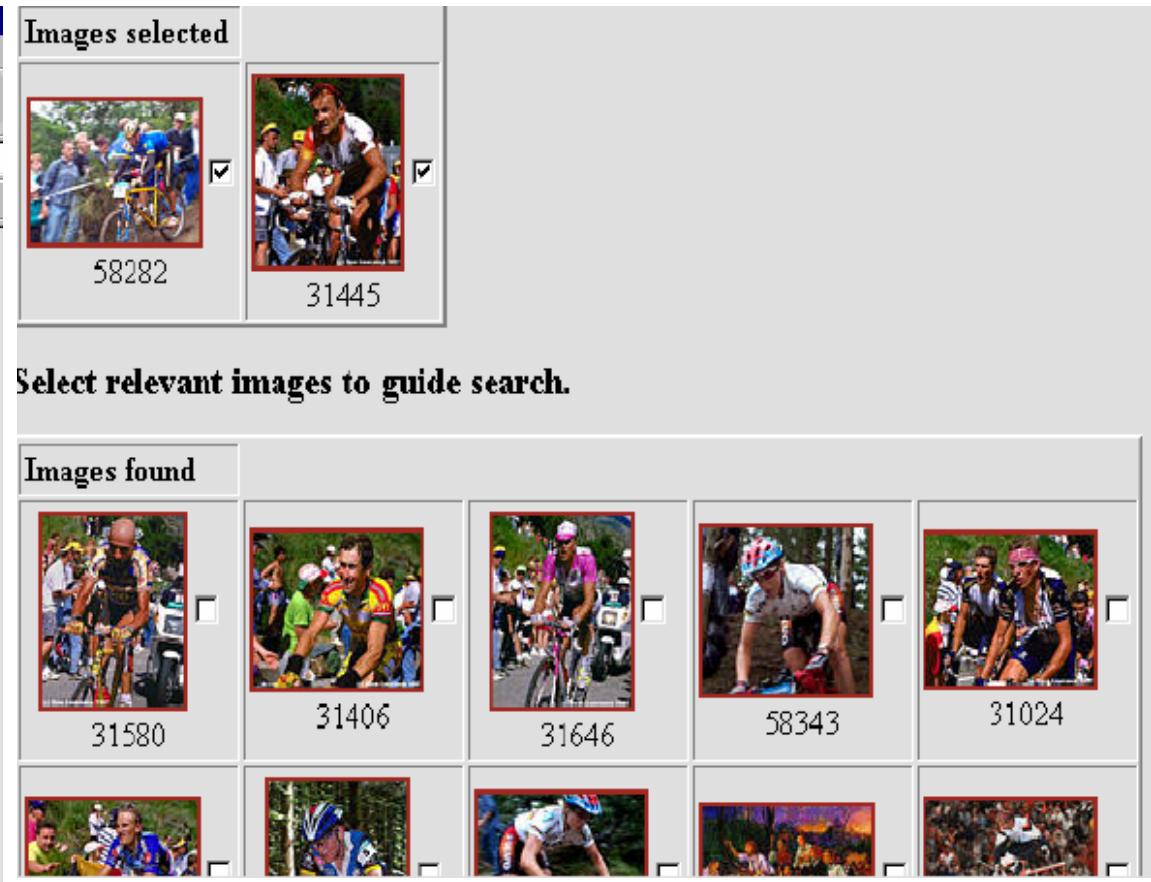
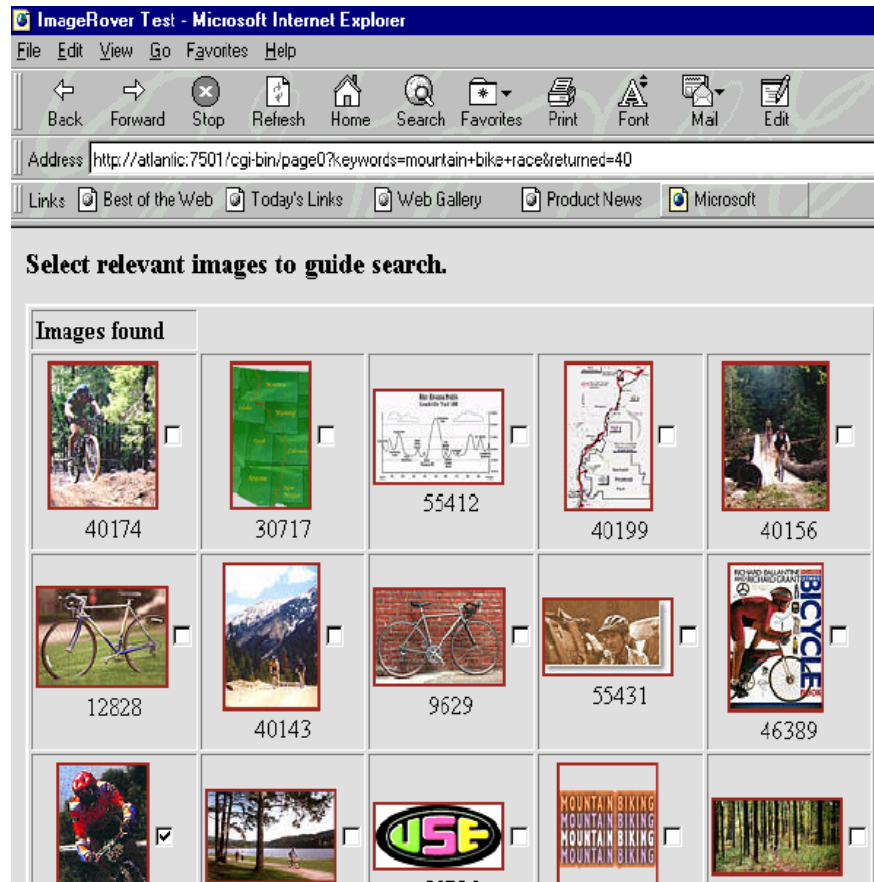
IDVL interface returned for "bin ladin" query.

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

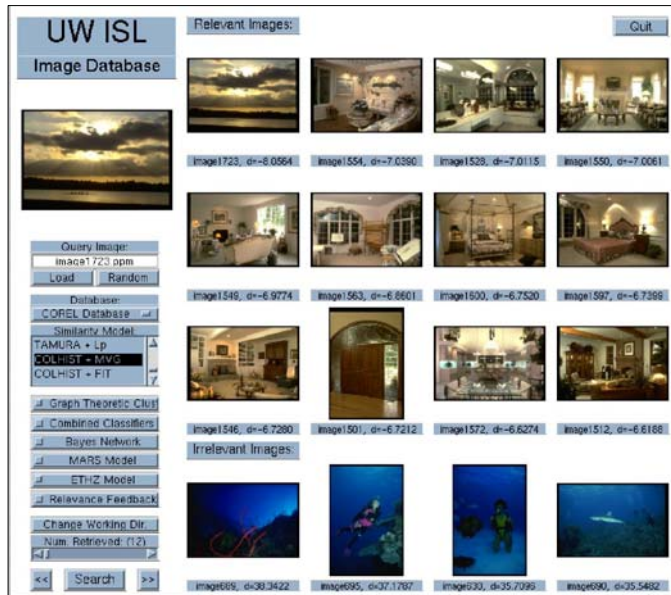
## ■ Positive feedback

$$\begin{aligned} p(A \mid \xi_{(0)}, \xi_{(1)}^+, \dots, \xi_{(n)}^+) &\propto p(\xi_{(n)}^+ \mid A) p(A \mid \xi_{(0)}, \xi_{(1)}^+, \dots, \xi_{(n-1)}^+) \\ p(B \mid \xi_{(0)}, \xi_{(1)}^+, \dots, \xi_{(n)}^+) &\propto p(\xi_{(n)}^+ \mid B) p(B \mid \xi_{(0)}, \xi_{(1)}^+, \dots, \xi_{(n-1)}^+) \end{aligned}$$

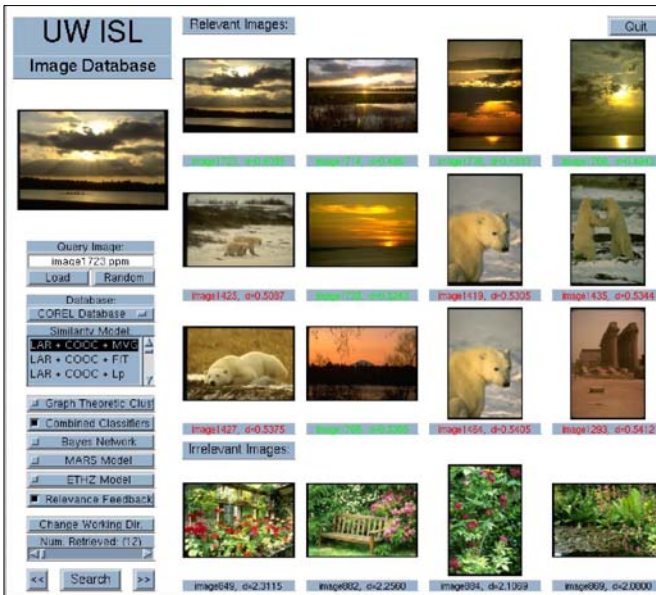
## ■ Negative feedback

$$\begin{aligned} p(A \mid \xi_{(0)}, \xi_{(1)}^+, \dots, \xi_{(n)}^+, \xi_{(1)}^-, \dots, \xi_{(m)}^-) &\propto \\ &\quad p(\xi_{(m)}^- \mid B) p(A \mid \xi_{(0)}, \xi_{(1)}^+, \dots, \xi_{(n)}^+, \xi_{(1)}^-, \dots, \xi_{(m-1)}^-) \\ p(B \mid \xi_{(0)}, \xi_{(1)}^+, \dots, \xi_{(n)}^+, \xi_{(1)}^-, \dots, \xi_{(m)}^-) &\propto \\ &\quad p(\xi_{(m)}^- \mid A) p(B \mid \xi_{(0)}, \xi_{(1)}^+, \dots, \xi_{(n)}^+, \xi_{(1)}^-, \dots, \xi_{(m-1)}^-) \end{aligned}$$

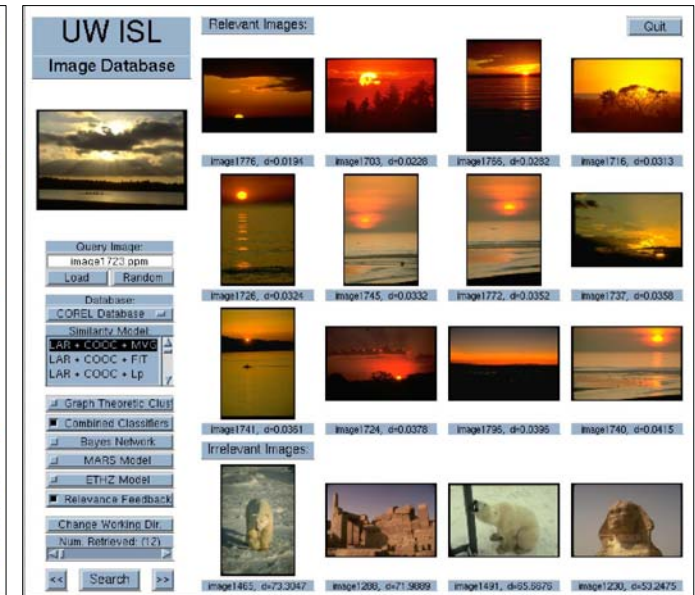
# Relevance feedback



"Sunsets" using color histograms  
(1/12)



Using combined features (6/12)



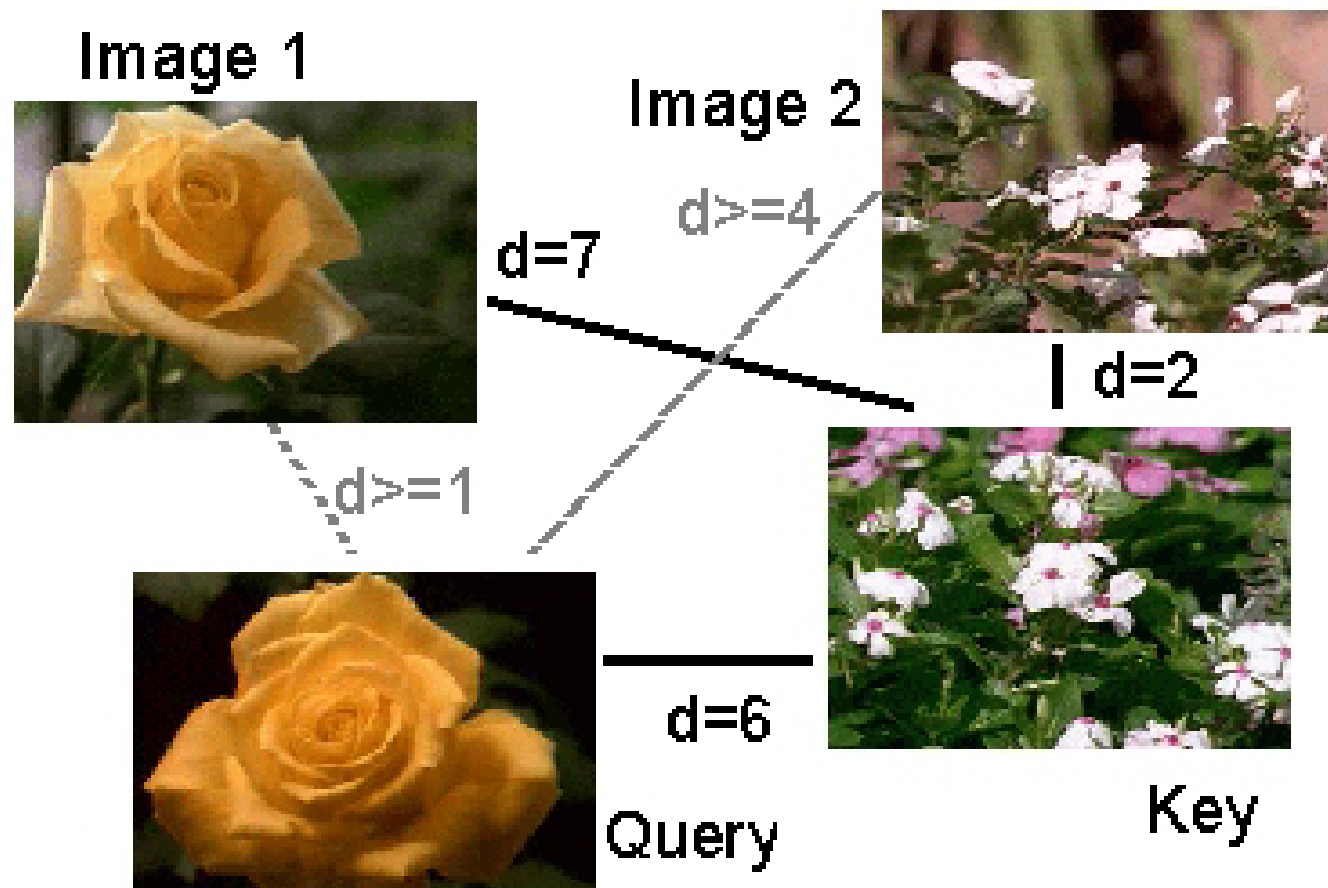
After 1<sup>st</sup> feedback (12/12)





# Indexing for fast retrieval

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



# Indexing for fast retrieval

---

## ■ Offline

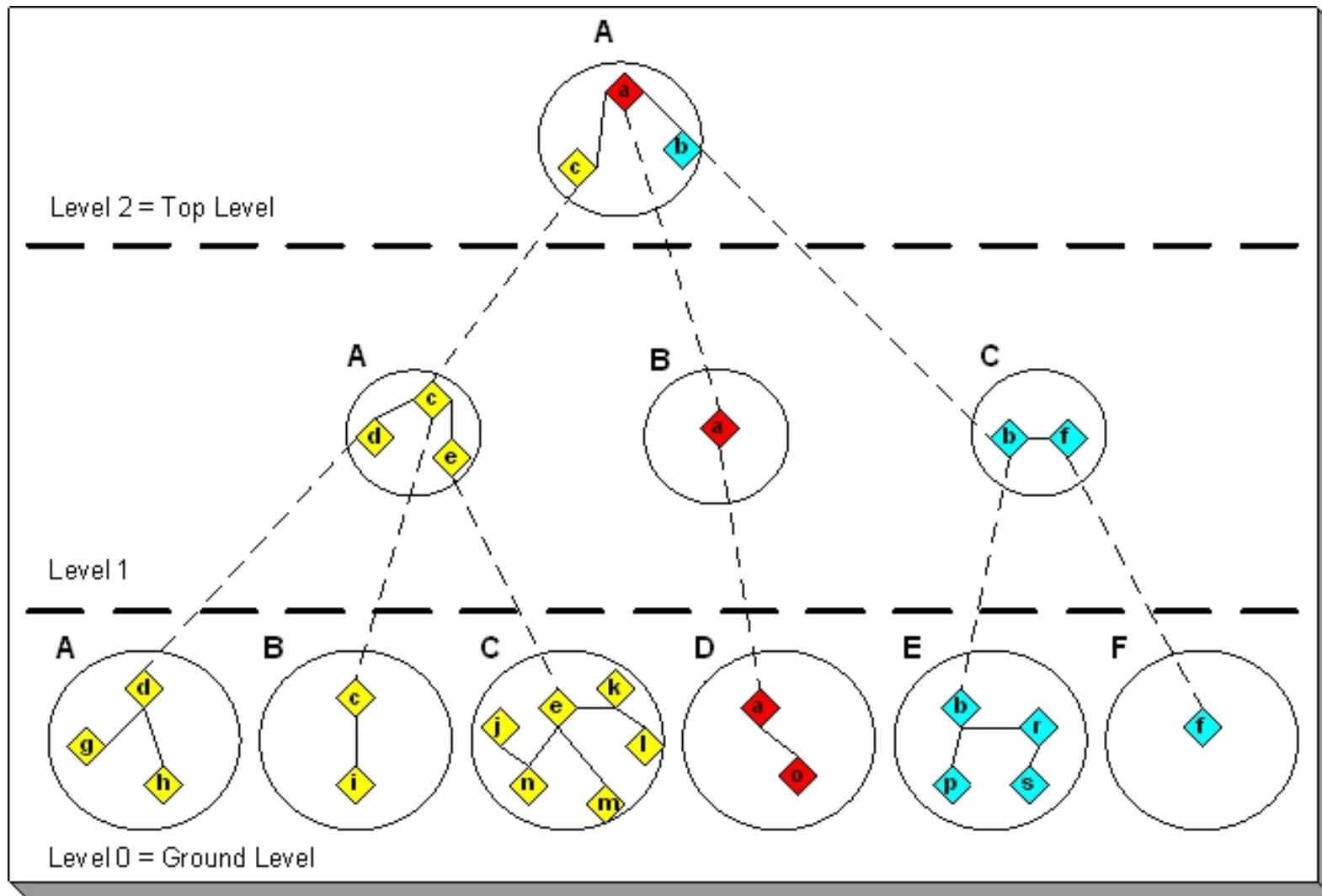
1. Choose a small set of key images.
2. Store distances from database images to keys.

## ■ Online (given query $Q$ )

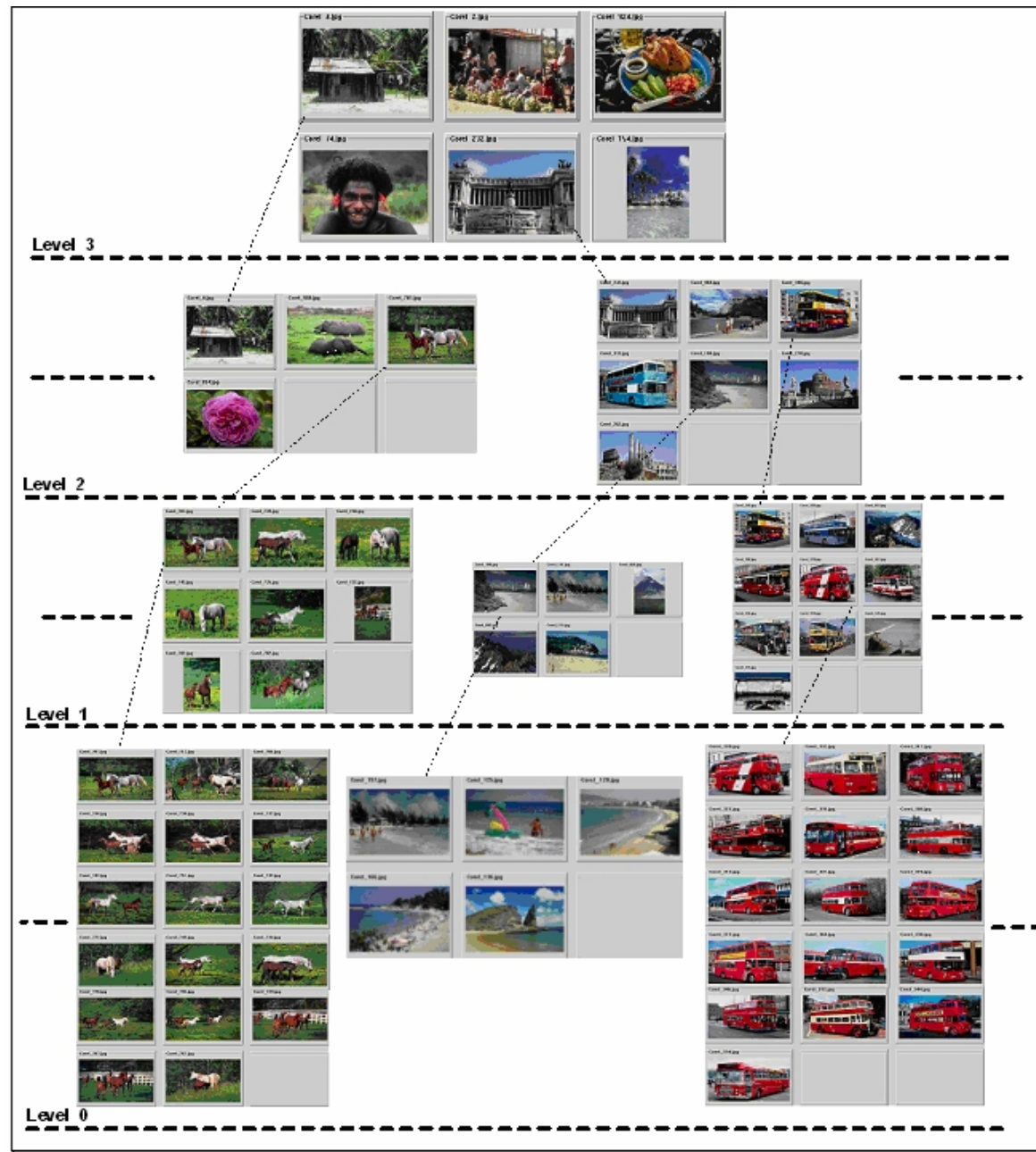
1. Compute the distance from  $Q$  to each key.
2. Obtain lower bounds on distances to database images.
3. Threshold or return all images in order of lower bounds.

# Indexing for fast retrieval

- Hierarchical cellular tree



# Indexing for fast retrieval



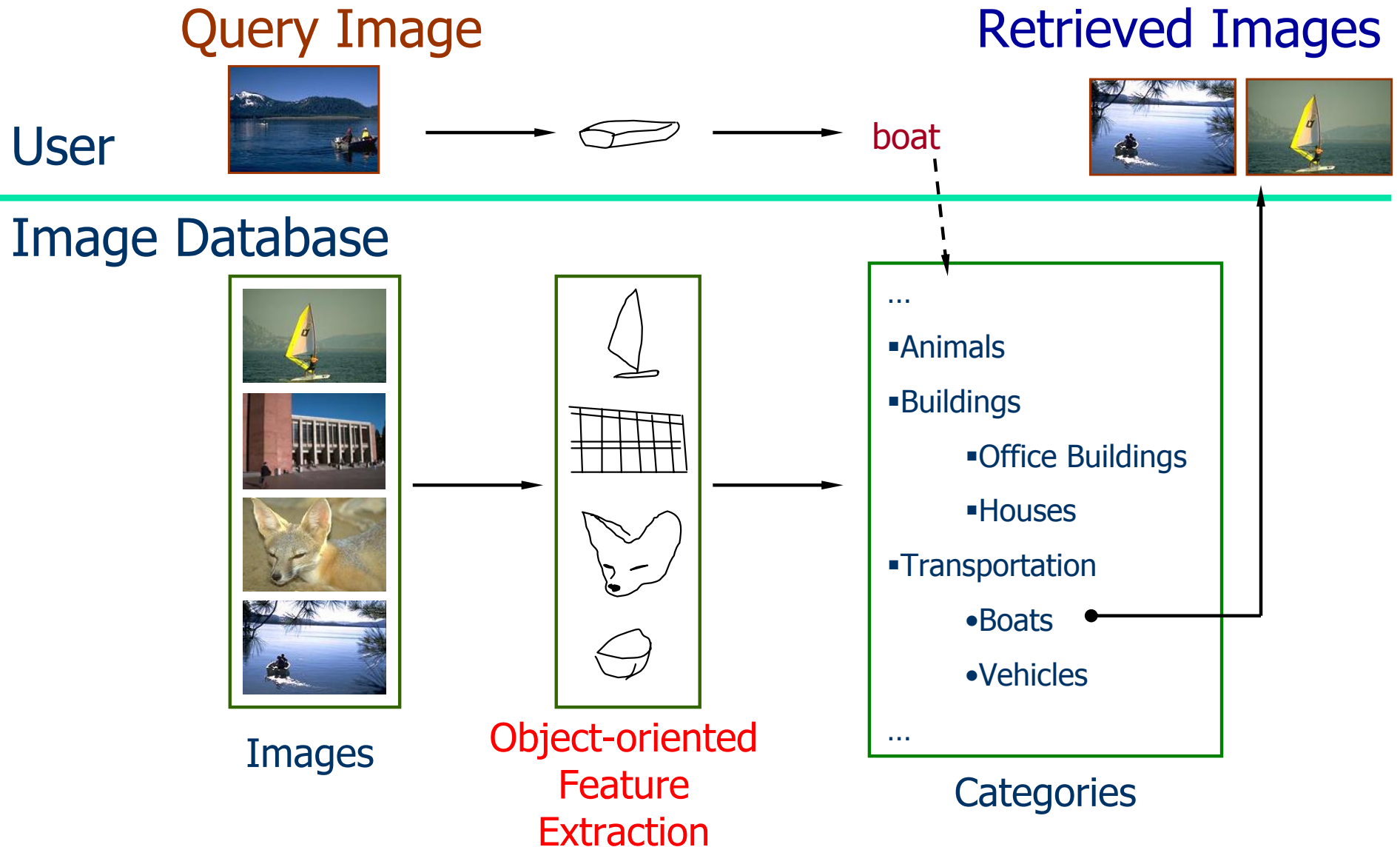


# Performance evaluation

---

- 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/>)