INSTITUTE OF INFORMATION AND COMMUNICATION TECHNOLOGIES
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1869

Rapid and Reliable Content Based Image Retrieval

(or FANTIR – the Fast & Noise Tolerant CBIR Technology of IICT-BAS)

a presentation by D. Dimov
(Assoc. Prof., PhD, IICT, BAS)

at Computer Vision and Multimedia Lab
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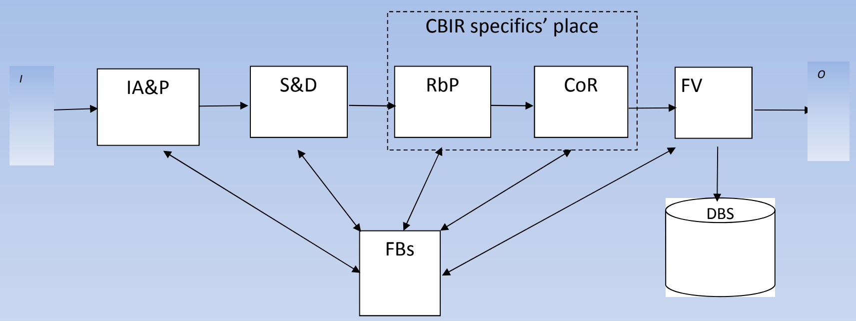
Introduction

- This presentation aims to demonstrate the system EFIRS (Experimental Fast Image Retrieval System), a development of the SP&PR department of IICT-BAS.
- EFIRS can be associated with the so-called “early” CBIR (Content Based Image Retrieval) [3,4,5,6, 8], but the experiments show that it can be successfully extended into the aspect of CBOR (Content Based Object Retrieval), i.e. for visual signature based [2] or view based [1] or multiple projections based 3D recognition [d1].
- FANTIR (see e.g. http://www.invenia.es/tech:ob-0121) is an earlier issue of EFIRS.

CBIR Description in Brief

- Content Based Image Retrieval (CBIR) covers methods, techniques, and tools for automatic (or automated) retrieval of images by content description based on simple features as color, texture, shape, movement, etc., as well as on structures over them.
- Each CBIR system comprises a Database of Images (IDB). The system should provide content-based image access methods that are *enough fast and reliable* from an user viewpoint. And preferences are on indexed access instead of sequential ones.
- CBIR can be also considered a basic *approach to pattern recognition* that uses a large dictionary of image instances. This approach accents on preprocessing of images for adapting the applied recognition technique to the conventional retrieval methods of the DBMS used (to maintain the IDB of interest).

CBIR Description in Brief …



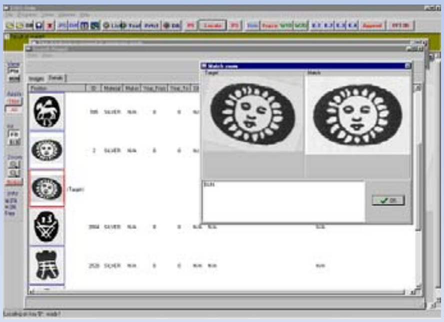
A general interpretation of CBIR from a viewpoint of IAPR (Image Analysis & Pattern Rec.): (IA&P) = Image Acquisition & Preprocessing, (S&D) = Segmentation & Decomposition, (RbP) = Recognition by Parts, (CoR) = Composition of Result, (FV) = Final Verification, with a DB of Standards (Examples), and (FBs) = possible Feedbacks**.**

CBIR Description in Brief …

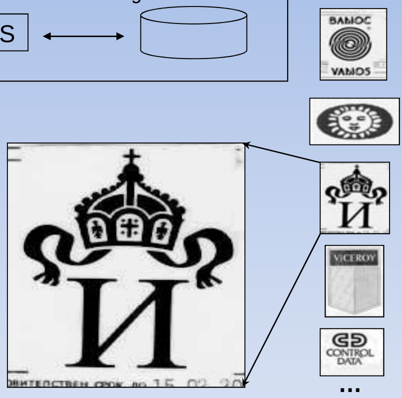
- Nevertheless the low-level (or early) CBIR could not overcome the so-called "semantic gap" between low-level visual features and high-level semantic concepts, just this *primary CBIR* should be a natural base for the next CBIR levels development, namely the so-called logical and/or abstract levels [3].
- There exist a lot of open CBIR problems, for which decision it is enough to have a rapid and robust basic access method into given DB of images (IDB). Image query by example into IDB of *hallmarks* is a classical task in this respect [4].
- Generally, the EFIRS' access methods generate adequate image descriptors, for using them directly as *conventional keys* for fast index search in the given IDB. This approach assures either high processing speed of the methods, or their reliability based on distance combinatory over the linear order of image keys.
- The most effective EFIRS method based on our Polar-Fourier-Wavelets Transform (PFWT) definition is described incrementally hereinafter. PFWT method allows both advantages, high invariance towards accidental input image rotation, and low correlation among the transform coefficients.

EFIRS – an Experimental Fast content based Image Retrieval System

input image *image content to a key* **EFIRS** *index key access* DBMS *Image DB of PORB*



A result of EFIRS in operation



A few images from the DB of PORB (the Patent Office of Republic of Bulgaria)

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EFIRS: The images of interest

Arbitrary images, gray scaled or true color ones, where the essential object(s) are situated close to the image centre, and a simple background surrounds them.

(a) a halftone image [12]

(b) almost B/W image with a rough noise of surrounding artifacts [13]

(c) a color image [13]

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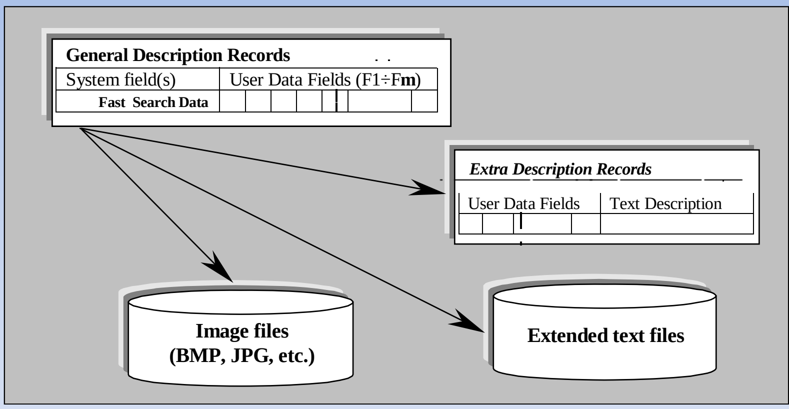
The IDB of EIRS (a simple logical scheme)



A demo of EFIRS can be demonstrated herein, see also App.1.

About the conventional index access method used

Fast DB access methods work using the DB convention of a "*key*". They give the search result as follows:

$$\langle \text{the key value of the retrieved object (record)} \rangle \prec$$
$$\prec \langle \text{the key value of the searched object (record)} \rangle$$

where "(i) $\prec$ (ii)" means "(i) is the greatest value less than or equal to (ii)".

Intuitive Requirements to the image key performance

An intuitive *definition*: The *image key* or simply the *key* should consist of the most essential information of given image, structured in descending order into a one-dimensional (1/D) array of fixed length.

Requirements to the image key definition:

- The key should consist of the (most) essential information of the image.
- This key information should be of significantly smaller volume than the image itself.
- The key information volume should be written in a 1/D array of fixed length.
- The key information should be structured in a way that *essential parts to appear in frontier positions* (from user viewpoint).
- The image key is not obligatory to be unique, i.e. for a given key length there can be more than one image to correspond.
- All DB images of one and the same key should be considered as equivalent images.
- The key length should be chosen in such a way that the image key to be enough informative one (from user viewpoint).

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EFIRS: CBIR Techniques for Fast Access into IDBs

Three basic types of CBIR techniques has been envisaged initially:

(**T1**): by a heuristic decomposition of the images to contextual contour parts, the 1DFT over the tree-of-contours (ToCFT)

(**T2**): by a two-dimensional wavelet transform (2DWT),

(**T3**): by a 2D Fourier transform (2DFT) as well as heuristic modifications, like *PFWT* (finally aimed herein).

Common principles for these CBIR techniques:

- The search content is the input image itself or a sketch of it.
- The most essential image data are automatically extracted and arranged in a ***key* string** of a fixed length.
- The fast access is performed on this key data using ***conventional index access methods*** of the DBMS of current use.
- Noise tolerance is treated in one and the same way by each of the techniques, i.e. simultaneously with the processing speed performance.

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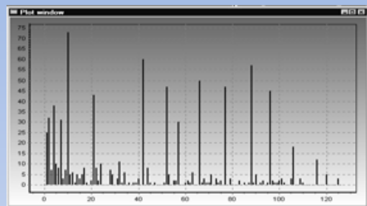
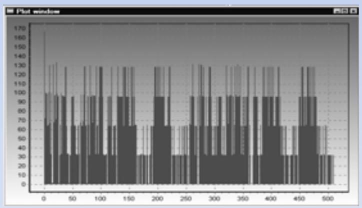
EFIRS: Image key derivation

A visual comparison of 3 type of keys

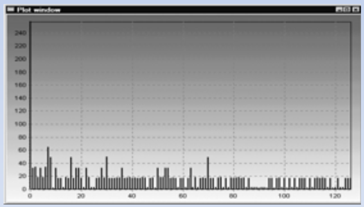
An input query (a mark image obtained from [12]).



(**T1**): resp. ToCFT key
(i.e. by a 1D Fourier's transform on the image's Tree of Contours).



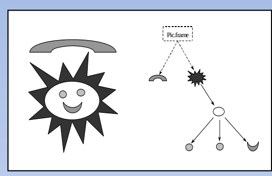
(**T2**): resp. 2DWT key
(i.e. by a 2D Wavelets' transform on the whole image).



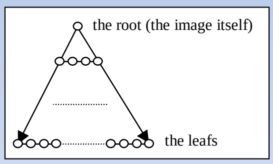
(**T3**): resp. 2DFT key
(i.e. by a 2D Fourier's transform on whole image).

A few details about the 3 techniques developed:

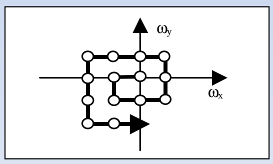
(T1): ToCFT: (this was FANTIR)
Image :-> ToC (the Tree of image Contours)
:-> 1DFT to ToC
:-> a heuristic arrangement of the frequency modula
:-> IDB key



(T2): 2DWT:
Image :-> 2DWT of the image (WT package, a quad-tree of decomposition)
:-> consider only the leafs
:-> order them by "importance"
:-> IDB key

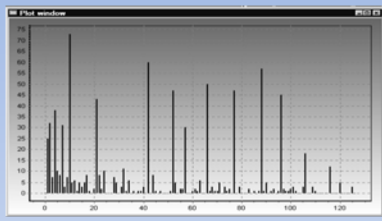


(T3): 2DFT: (this is the base of PFWT)
Image :-> 2DFT of the image
:-> scan appropriately the 2d frequency space
:-> IDB key



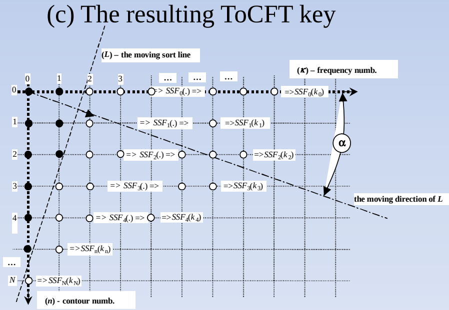
(T1): the ToCFT technique for image key derivation

(a) The chosen query image.

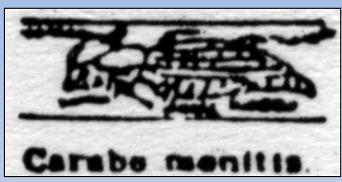


(c) The resulting ToCFT key

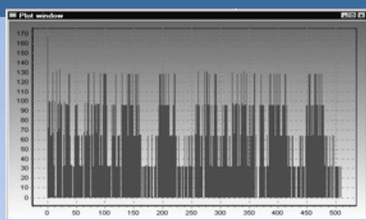
(b) All contours of the image, and its contours appropriately arranged, [d7]



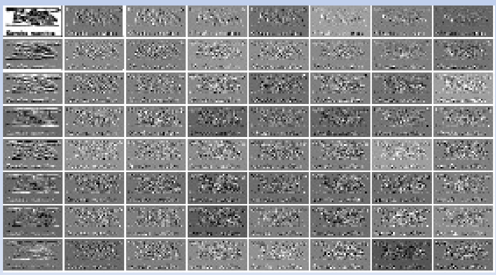
(T2): the 2DWT technique for image key derivation



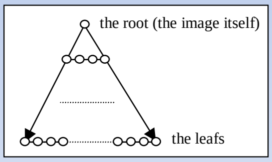
(a) The chosen query image.



(c) The resulting 2DWT key

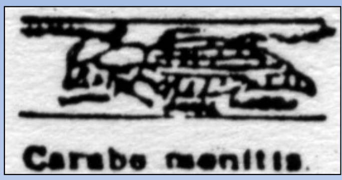


(b) 2D Wavelets' transform on the binarized image,

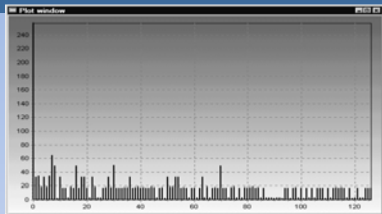


... only leafs of 3th level are shown (for better visibility), [d8].

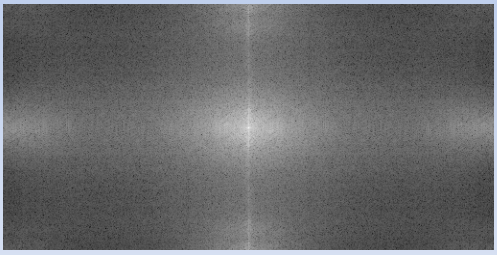
(T3): the 2DFT technique for image key derivation



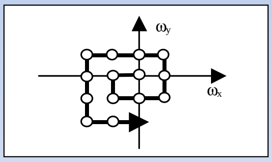
(a) The chosen query image.



(c) The resulting 2DFT key



(b) 2D Fourier's transform on the binarized image (modula-spectrum in a logarithmic scale),



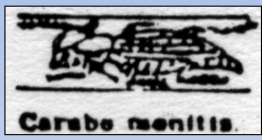
... and the scheme of key derivation.

Invariance to accidental linear transform of images that EFIRS operates

- Focus on the rotation invariance – against possible accidental rotation of input images, nevertheless of being either input queries or images already kept in the IDB.
- The other type of invariance – against translation, scaling, mirroring and/or illumination irregularities can be considered resolved by preliminary evaluation and/or compensation. This approach is considered inappropriate to realize rotation invariance, cf. also [10]. Internal integration of rotation invariance within the key derivation techniques is necessary.
- Integration of rotation invariance within EIRS techniques:
  - in T1 (ToCFT) – resolved by the definition of 1DFT applied to ToC (the tree of contours). But it has noisy troubles with very close couples of contours, [d7];
  - in T2 (2DWT) – principal difficulties for integration because of the 2DWT definition (nevertheless the good properties for noise tolerance organization in EFIRS), [d8];
  - **in T3 (2DFT)** – the most promising for both the rotation invariance integration and the good properties for noise tolerance organization;
  - The PFWT is proposed [d3] as modification of P2DFT, because of P2DFT is considered already known Fourier-Mellin Transform, [14].

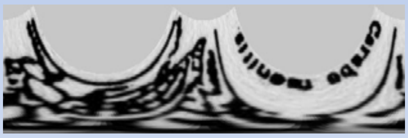
Polar Mapping (PM) of images:

PM is an effective approach to include a rotation (and/or scale) invariance in the CBIR techniques.



(a) An original mark image:

Image Centre of Gravity (CoG) is usually chosen for PM centre.

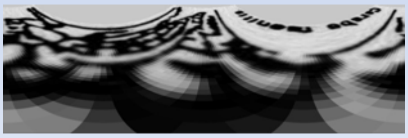


(b) Simple Polar Mapping (SPM):

$$P: Z \to Z,\ P(x,y) = (\rho,\theta),\quad (x,y) \in Z,\quad (\rho,\theta) \in Z$$

$$\rho = \sqrt{x^2 + y^2},\ \theta = arctg(y/x)$$

(!) Image rotation around the CoG converts into angle translation in SPM.
(!!) *To be used for rotational invariance*

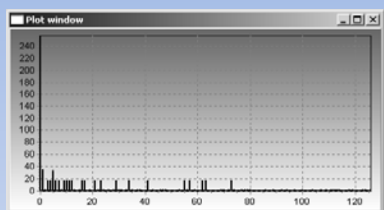


(c) Logarithmic Polar Mapping (LogPM): additionally to SPM we have: $\rho := \log(\rho)$
(!!) Additionally the image scale converts into distance translation in SPM.
(!!!) *The latter not very preferable practically because of lower precision.*

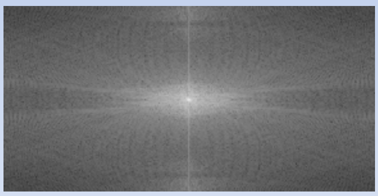
(T3a): A Rotation invariant extension of the 2DFT technique

(T3a) := SPM + 2DFT

(a) An original mark image.



(c) The resulting SPM-2DFT key

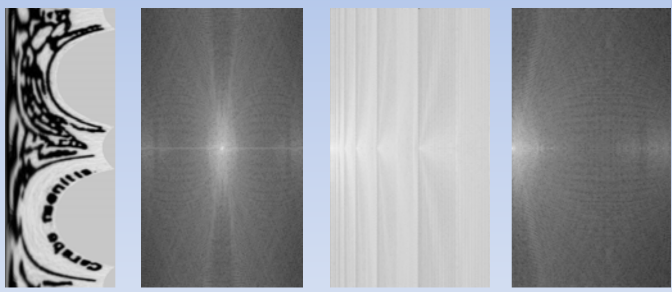


(b1) Preliminary SPM of the binarized image, and
(b2) 2DFT (by logarithmic scale for modula-spectrum).

Two more extensions of 2DFT technique:

(T3b) := PFWT = SPM + FT + WT; FT on angles (vertically), then get modula and finally a WT on distances (horizontally).

(T3c):= SPM + FT + CosFT; another version: CosFT instead of WT, on distances (horizontally)



SPM (2DFT) (FT + WT) (FT + CosFT)
(modulo-spectra in a logarithmic scale for better visibility).

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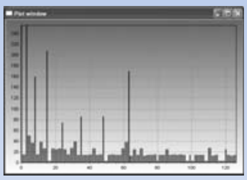
An image and its rotation processed by both methods of comparison, PFWT and P2DFT

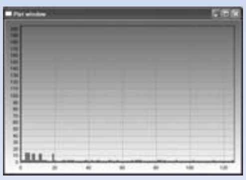
An accidental rotation

is converted into a translation in the respective SPM,

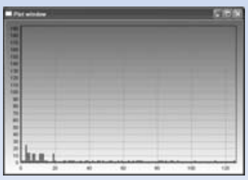
and almost no differences can be met in the PFWT key,



Note that PFWT key consists of much more essential values that better identifies the input image



and a small difference is only visible in the P2DFT key (caused by sampling)



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EFIRS, application for the IDBs of PORB

Trademark examples from the current practice of Bulgarian Patent Office (PORB): A test IDB of ~60 000 trademark images is currently explored for the EFIRS test, and 15 of them are shown hereinafter, derived in 5 typical categories:

(1) Enough clean images

(2) Relatively clean images

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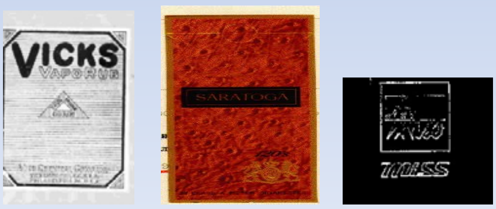
EFIRS, application for the IDBs of PORB...

(3) Multicolor and/or halftone images

(4) Images with a great level of artifacts



(5) Very dirty images

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The EIRS techniques' restrictions:

- The techniques are restricted to pictures containing of well-localizable essential sub-image (i.e. a gray scale or true colour object, or a set of such objects, vs. the image rest considered as picture background).
- If the pictures contain a great level of noise, and especially an "artificial" noise (artefacts), they should be suppressed preliminary like in [d5, d6].

EFIRS, other possible applications

Extensions/Modifications of EFIRS for 2D applications in:

- numismatics
- banking, bond-hobbies
- philately
- forensic expertise
- machinery design
- …

EFIRS can approach 2 general versions of IDB performance:

- a local IDB: cf. COVERIS and or FANTIR technology offers.
- a distributed IDB, e.g. for Internet applications, etc.

The EFIRS IDB should be considered (can be organized) like an extra patch to given IDB performed on arbitrary DBMS (DB Management System).

EFIRS: Possible application in Cultural heritage archiving

- a lighter possibility: IDB for initial letter images of Middle Century.
- and more difficult possibility: IDB for old coins' images.

Four examples of the old Cyrillic initial letter "K" (obtained from www.omda.bg/bulg/hystory/initials.html)

Six examples of old Bulgarian coin minting (Appollonia, Messambria, and Odessos, III – I c.B.C.) (obtained from http://topalov.hit.bg/main-bg.htm)

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EFIRS: Possible application in banking and/or bond-hobbies

1$, 2$, 3$ …
(Where is the forgery :)

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EFIRS, other possible applications

Extensions/Modifications of EFIRS for 3D applications:

- Face recognition (for pass control systems)
- Sign languages recognition (to help hearing impaired people)
- …

- from 2D CBIR to 3D CBOR (Content Based Object Retrieval). Possible pivot application – in cultural heritage preservation of archeology, by analogy with EFIRS for face recognition, …

- to understand the way how human vision helps brain to learn new objects and/or to recognize already known ones, using eye tracking approaches to structure the respective object elements given in an IDB,…

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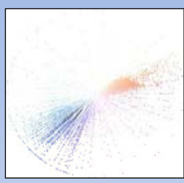
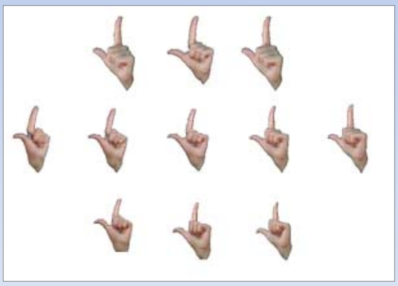
EFIRS applied for 3D objects recognition

For more details see [d4]



HS-histogram of a given frame.

For more details see [d1, d2]



A demo of EFIRS based Face recognition is ready for showing

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Conclusion

- The basic idea of EFIRS is to represent the essential image content as a well-structured DB key of fixed length, namely – the more important image data to take more front positions in the key.
- Two basic techniques have been developed by this approach at the present:
  - Fast Image Retrieval by the Tree of Contours' Content,
  - and by Polar-Fourier-Wavelet transform (PFWT).
- The restriction of the EFIRS method – for well segmentable objects only.
- The method can be considered as nearest-neighbor recognition method, i.e. by closeness to the examples in an IDB.
- The method is well adapted to conventional indexing access methods of conventional DBMS (DB Management Systems).
- The method can be applied as image search engine in a conventional DB of images, for instance in information and image retrieval systems for marks, hallmarks, trademarks, postmarks, Cultural heritage archiving, etc.
- Because of its effectiveness, the method is well extendable for 3D objects recognition via DB of multiple 2D projections of the objects of interest.

Conclusion

- Expecting for your questions, remarks, notices, etc., to complement and finalize the conclusion…

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THANK YOU !

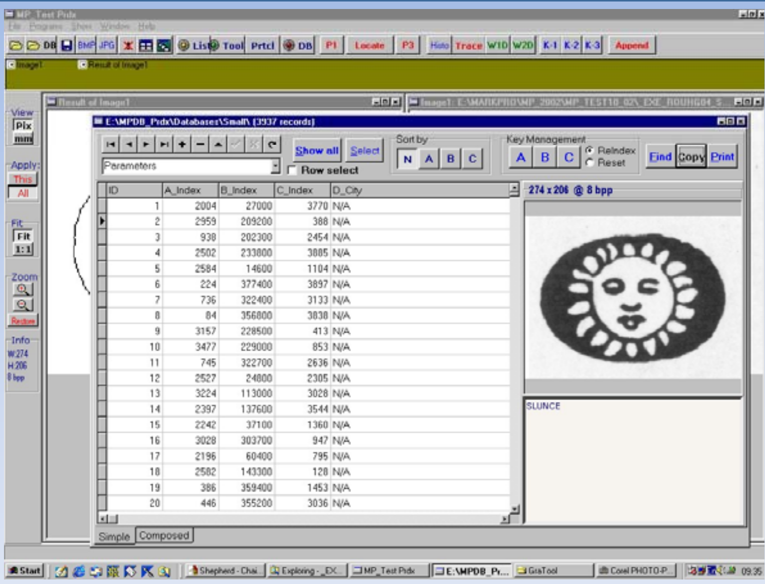
App. 1

The EFIRS system (a DEMO)

- If the Demo is not possible show next 4 slides:

- EFIRS: the IDB browser
- EFIRS: the Search-engine start menu
- EFIRS: the Search engine (result table I)
- EFIRS: the Search engine (result table II)

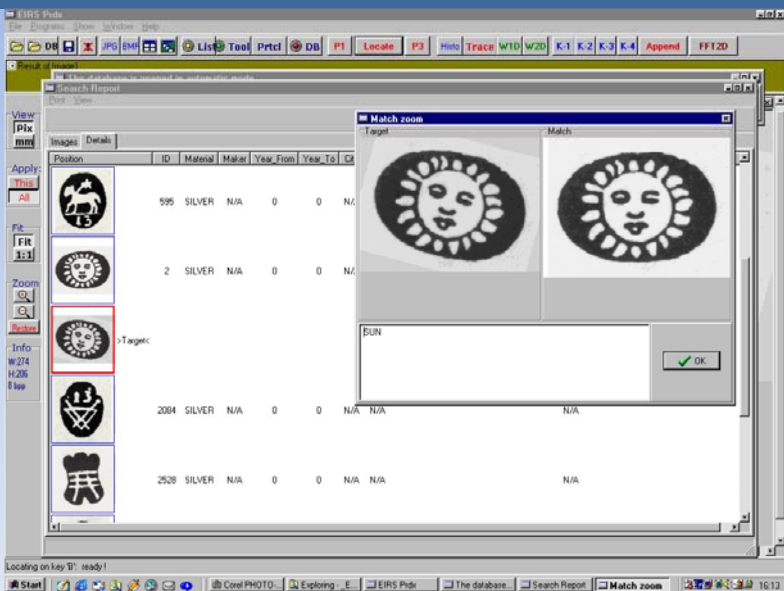
App.1: EFIRS, the IDB browser



App.1: EFIRS, the Search-engine start menu

App.1: EFIRS, the Search engine (result table I)

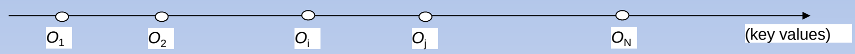
App.1: EFIRS, the Search engine (result table II)



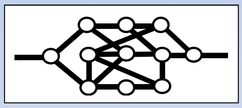
App.2: What is the EFIRS approach excellence in

The convention for the DB object's keys:

$K(O)$ - a value associated to O (an object)
A simple key example: a (sequence of) feature value(s)
DB index <-> ordering the objects by their keys, i.e. a full ordering:



The usual CBIR practice:

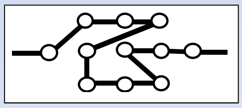


A specific similarity function (S) or distance function (D) (usually not a metrics) to compare given input image (input object) with all the DB images (objects).

The above techniques usually lead to

(1) a partial ordering, i.e. to a sequential access into DB, of an access time ~ N = |IDB|

while **the EFIRS approach leads to**



(2) a full ordering, i.e. to a DB primary key index, of an access time ~ $\log_2 N$, N =|IDB|,

what is the main advantage of the EIRS approach (!)

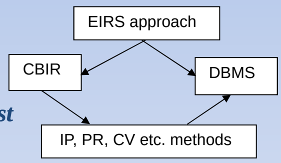
App.2: What are the EFIRS approach advantages

How the EFIRS approach defines full order (in the set of IDB keys):

$$K(O)=\sum_{i=1}^{n} x_i M^{n-i} \quad , O \equiv (x_1, x_2, \ldots, x_n)$$

where x_i , $i = 1 \div n$ are the O-object features ordered by "their importance"
(for the current application of EIRS, or for the user imagination about it)

Conventional CBIR approaches for accessing an IDB:



- z-filling curves (a way of scanning the feature space)
- k-trees, R-trees, etc. heritage from GIS (Geographic Information Systems)

All they do not match the necessities of an effective (fast and noise tolerant) CBIR (!)

Similarities among objects:

Similarity function S. Distance D.

$S(A,B)$ ~ 1 / $D(A,B)$, where A and B are given objects.

Mahalanobis distance (Gaussian model of errors over given object or class of objects, and primary it's not a metrics).
Euclidean distance (also often used, because it defines a metrics)

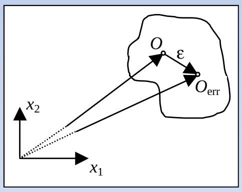
App.2: What are the EFIRS approach advantages

Squeezing the feature space dimension (*n*):

Simple approaches:
Reorder the feature space coordinates (or choose from all *n*! possible orders):
- Put the most important coord's at front positions and cut the rest of "not so important" coord's.
- More sophisticated approaches: e.g. Karhunen-Loeve (KL principal components analysis (?)

The place of EIRS approach in the CBIR area :

- Searching an object into a DB => Method (or system) for PR (Pattern Recognition), or a DB access method, i.e.
- An object of given DB => A standard object (example) or a center of a class (of given type of objects)



$$O_i \in C_i \subseteq \bigcup_{j=1}^{n} C_j \quad , i = 1 \div n$$

$$C_i \bigcap Cj \quad , i \neq j$$

…

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App.2: EFIRS, Noise Tolerance Interpretation

- (Approximated) representation of objects by their features.

- Vector representation (of extracted features, e.g. colors, geometric measures, histograms, frequency components, wavelet components, etc.):

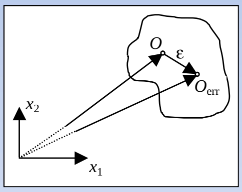
$O \equiv (x_1, x_2, ..., x_n) \in \mathbf{E}^n$, n – number of coordinates of $\mathbf{E}^n$

- Noised objects processing:

$O_{err} = O + \varepsilon \quad , \varepsilon \equiv (e_1, e_2, ..., e_n) \in \mathbf{E}^n$

- A sufficient condition for a recoverable noise

$$D(O,\, O + \varepsilon) \;\leq\; d_{\min} = \frac{\min\{D(A, B) \mid A, B \in \mathbf{E}^n\}}{2}$$



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App.3: Experimental results

Test results of 3 IDBs of PORB (IDB1 ⊂ IDB2 ⊂ IDB3)

Access method	IDB number of images	Total of errors (warnings + essentials)	Essential errors only		Retrieval time (per image of IDB)		IDB init (first time only)
			their number	as % of IDB volume	Average [s/rec.]	Max [s/rec.]	[s]
P2DFT	4834	954	48	1.0	0.54	3.45	0.8
	30001	8352	344	1.2	1.17	8.58	7.9
	58338	16682	494	0.8	1.97	19.31	12.3
PFWT	4834	782	100	2.1	0.64	3.47	2.0
	30001	7272	698	2.3	1.24	8.91	7.5
	58338	14692	1066	2.3	1.85	20.22	12.5

Experimental results (some notes)

(1) **Test methodology**: Each image of the given IDB is regularly noised (intentionally rotated and scaled) before using it as input content to search in the same IDB. Thus, the number of all experiments is N, N=|IDB|.

Warnings: communicate that the (most similar) first retrieved image differs from the input content, but the right image exists in the image set retrieved by the CBIR method chosen. Reasons: (i) the IDB consists of many similar images; (ii) the comparison depth parameter should be incremented for this IDB.

Essential errors: the most similar retrieval differs from the input content and the right image does not exist in the image set retrieved the CBIR method. Reason: the method is not appropriate (for this case).

(2) ***Retrieval time***: includes the time for image key derivation from the input image content, plus the time for fault-tolerant search into the IDB using this key, plus retrieval and visualization time for the set of found (retrieved) images.

The ***average retrieval time*** evaluated over the all experiments (entire IDB), it obeys the theoretical estimation of ~ $\log_2$|IDB|.

The ***maximal retrieval time*** corresponds to the largest image at the input, i.e. the key derivation time can be evaluated/parameterized from the difference between the retrieval time maximum and average.

IDB init (initialization for search): it should be performed starting once at given IDB and depends on the DB Management System used, in this case - Borland Paradox.

The timing depends on the resources used, in this case: CPU Intel P4 2,8GHz, DDR SDRAM 2 GB, HDD 160 GB.