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Content-based image retrieval tools and techniques

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Content-Based Image Retrieval Tools and Techniques

In the beginning was an image.

To my mother
who inspired me
to develop intellectually

Contents

7 Data Base

7.1 Introduction

All the below-described search engines (see Chapter 9) have to use image collections (sets of images) or databases containing not only images. The concept of storing information varies in different systems from the top secret military images up to free use Google images.

As we have shown in Fig. 2.5 describing the general CBIR architecture, each system consists of different: image collections, features, descriptors, auxiliary data, etc. Information from all of them is gathered in a data base. The relational model of data permits the database designer to create a consistent, logical representation of information.

A database management system (DBMS) is computer software designed for the purpose of managing databases. A DBMS can be characterized by:

1. A modelling language to define the schema of each database hosted in the DBMS, according to the DBMS data model.
2. The optimal structure depends on the natural organization of the application's data, and on the application requirements (which include transaction rate or speed, reliability, maintainability, scalability, and cost).
3. Data structures (fields, records, files and objects) optimized to deal with very large amounts of data stored on a permanent data storage device (which implies relatively slow access compared to a volatile main memory).
4. A database query language and report writer to allow users to interactively interrogate the database, analyse its data and update it according to the users' authorized access to data.
5. The security control unit of the database.
6. Data security preventing unauthorized users from viewing or updating the database. By using passwords, users are granted access to the entire database or its subsets called subschemas.
7. Providing a way to interactively enter and update the database, as well as interrogating it, which enables the user to manage their personal database.
8. Maintaining the integrity of the data in the database.

9. Maintaining the integrity of the database by not allowing more than one user or a process to update the same record at the same time. The DBMS can help prevent duplicating records via unique index constraints.

7.2 Benchmarking CBIR systems

The problem of CBIR evaluation has been a neglected topic for a long time because it is a very challenging task. The main stumbling block is the fact that even though CBIR systems consist of a number of components, not always the same, they depend on one central concept of a system. Nevertheless, over the past few years a multitude of CBIR systems has been developed and the difficulty of comparing their performance on an objective basis became apparent.

The field of CBIR technology lacks a generally accepted methodology of benchmarking (parts of) systems [175], despite several efforts to introduce standards (see sect. 3.7). Theoretical work explaining how the systems should be evaluated based on user relevance sets for a number of query images appeared off and on. However, particular performance measures or benchmark image DBs were not proposed and no example evaluation was given. For example, MIRA (Evaluation Frameworks for Interactive Multimedia Information Retrieval Applications, 1995 [175]) was the first project prepared at the University of Glasgow to take a more formal approach to the evaluation of Multimedia Retrieval systems.

In 1997, Narasimhalu [176] made a formal comparison of different sorts of CBIR systems, and in 1998, Smith [177] highlighted the necessity of a benchmark in CBIR where he proposed to use the TREC as a model. Unfortunately, no example evaluation was done. In 1999 Dimai [178] described a rank-based measure for comparing two different feature sets or CBIRs to overcome the shortcomings of precision and recall. The comparison of two systems might work, but in a benchmark framework many systems need to be compared. What is also important, the systems were not compared based on a single performance measure, but on several ones.

The numerous CBIR systems result in the lack of benchmarking image DBs and the methodology to compare the work of systems. As we show it in the next section, there are some image collections dedicated to testing only particular retrieval search engines. Generally, there should exist a common database for benchmarking, available free of charge, with no copyright available from the internet or in publications, and it should be sufficiently diverse and complex to satisfy the countless needs of CBIR system designers .

Additionally, in most cases the user is ignored in the benchmarking process, despite the fact that CBIRs are used and judged by their users. It is due to the fact that many different criteria of validation [179] need to be taken into account:

1. The methods should be appropriate to the kind of images and agreed with respect to the research goal.

2. All engines should be supplied with the same results interface, unless the interface is a topic of research;
3. The aspects under research should be assessed in isolation. Hence, each aspect or component can be separately judged on its contribution to the overall performance of the engine; so specialized systems (e.g., for medical image retrieval or fingerprints DB) can be tested only in their specialized fields. A benchmarking framework has to have maximum flexibility so it can be used for all the tests and testing of new parameters. Additionally, it can be easily adjusted to the different systems without designing a new benchmark.
4. A valid design of the benchmark should be developed. Therefore, the following aspects have to be satisfied:

   – Randomization of all queries;
   – A set of standardized queries should be selected and subsets should be assigned in different arrangements to each of the engines under research;
   – The number of judged queries should be large; then, variations in settings can be regarded as noise.

5. Alternatively, the benchmarks should be run in a controlled setting. Then variability in environment, display, light, etc. is under control.
6. The results of the search should be evaluated separately and independently to overcome possible differences in retrieval speed among the engines.
7. Real user evaluation – relevance judgements. Often, image DBs contain groups of images with the same objects ('trees', 'houses', etc.). However, a group of images can vary over a great range in such a way, that some images are more similar to another group. For instance, mountains at night can be more similar to a gothic cathedral at night than to mountains in snow on a sunny day. That is why there is a need for the real expert opinions, especially in restricted domains, such as medical image search. The process of getting relevance judgments can be available or even necessary in certain fields of real ground truth.
8. Benchmark objectivity - The ground truth data for the images and even the images chosen as query images should not be known by the benchmarked systems because a system can try to cheat when this information is available. If a system knows the image classes, it can of course always return a perfect response.

Now, we have to ask a question what element of CBIR can be evaluated in a benchmark because a CBIR system needs to test several tasks, not only one as a whole [175]:

1. Looking for a specific image - Systems have to demonstrate the capability to extract features from a given input image (or image segment). Also some systems search for a corresponding image in the image database indexed beforehand.

   – Search for an exact image from the database.
   – Search with a cropped part of an image from the database.

- Search with a geometrically altered (rotated, scaled, dilated or shifted) image from the database,.
- Search with an image a part of which is occluded.
- Search with a compressed image from the database, i.e., strong JPEG or TIFF compression.

These search methods can test the invariances of a retrieval system and especially the retrieval speed.

2. Looking for a number of similar images - The search for a number of similar images for a given query image is the standard query by example (QBE) evaluation.
   - Performance measure – precision (cf. (2.1)) and recall (cf. (2.2)) still remain the standard measures as they are easy to understand and interpret.
   - Evaluation of QBE with known relevance judgments.
   - Evaluation of several steps in positive or negative feedback.
   - Evaluation of how well a system can adapt the output for the same starting image but with different ground truth sets and thus different RF.
3. Looking for a sketch of an image – a system should be resistant, in general, to incomplete information, for instance, when the user draws a sketch, normally they concentrate on the object ignoring the background, and additionally, the time taken to draw a sketch is limited.
4. Target search (also called image browsing).
5. Practical application tests. An index of an image database can be generated and the time required for this is measured. Then, one or several images are added into the database, the index can be recalculated and a query with one of the images can be executed directly afterwards. Performance measures have to measure the efficiency of the system with respect to a given task related to:
   - Feature extraction and index generation;
   - Inserting an image into the database;
   - Inserting an image into the database and finding a known image similar to this one.
6. Measure the scalability of a CBIR system - For many applications it is important that a CBIR system can deal with very large databases in an efficient manner. In order to show the scalability of a system, the time for several actions and operations, such as feature extraction, index generation and image querying can be measured for several collection sizes, for example with 10,000, 100,000 and 1,000,000 images.
7. Performance measure - New performance measures can be easily added to the system to increase efficiency and accuracy.
8. Tests for special application areas - CBIRs from different application fields, with different characteristics, should be tested accordingly by specialized programs. For example, many medical images are black and white, whilst satellite images might need colour characteristics different from the ones used for stock photography.

9. Evaluation of CBIR interfaces - It might not be possible to evaluate the quality of CBIR interfaces completely automatically, but users can certainly determine how well the information is presented and how easy it is to give feedback or find groups of similar images. Measures for the quality of interfaces have to be developed. Interfaces in the 3D domain, such as Nakazato and Huang [26], show that interfaces for CBIRs can be studied much more than is the case at the moment.
10. Access to systems – for a benchmark DB there should be free access. The proposed method can be the multimedia retrieval mark-up language (MRML) similar to an XML-based communication protocol dedicated to CBIR, or simply SQL for DBs. There is also the problem of specialized DBs where access is closed for security reasons. The system can use any image database and also databases of other objects that can be specified by a URL as a unique identifier.

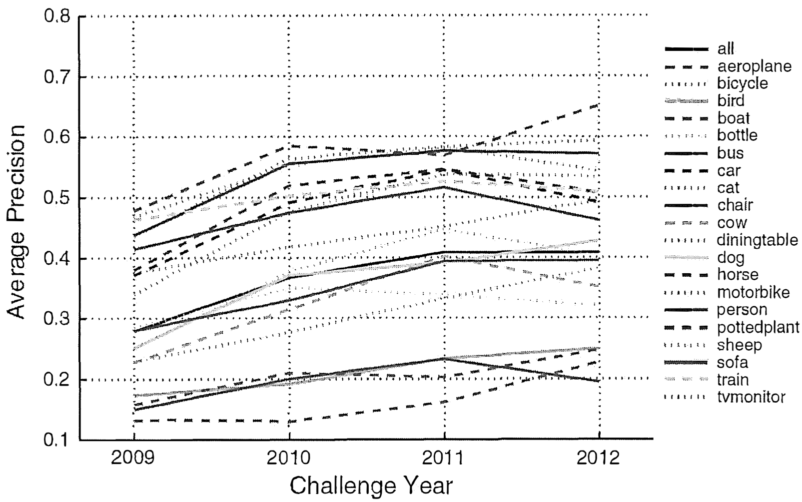

Fig. 7.1 For each year and class the plot presents the average precision at the object detection category obtained by the best-performing method in a particular class in a particular year [180] for participation in the Pascal VOC challenge.

One of the opportunities for benchmarking is the Pascal Visual Object Classes (VOC) Challenge [180] which has been an annual event since 2006. The challenge consists of two components: a publicly available dataset of images obtained from the Flickr website (2013), together with ground truth annotation and standardised evaluation software; an annual competition and a workshop. There are five challenges: classification, detection (example in Fig. 7.1), segmentation, action classification, and person layout. Here again the scattering is visible in the challenge categories.

7.3 Image Collections

Together with developing CBIR systems, the DB collections have been developed. Most of the freely accessible DBs have been offered by universities.

Some new systems use a subset of the *Corel image dataset* [181], others use either self-collected images or other image sets, such as LA resource pictures [182]. The Corel image database contains 10,800 images from the Corel Photo Gallery divided into 80 concept groups, ranging from animals and outdoor sports to natural sceneries. These images are professionally pre-classified into different categories. Each group includes more than 100 homogeneous images.

The *Kodak database* of consumer images [183] and Brodatz textures [184], [185] are widely used in perceptual texture feature studies. These databases contain a few hundred images with sets of different textures. Images collected from the Internet serve as a data source, especially for systems targeting Web image retrieval [186] [187].

The *Pascal Visual Object Classes* (VOC) consist of a publicly available dataset of images together with ground truth annotation and standardised evaluation software [180], [188]. The data is divided into two main subsets: training or validation data, and test data. There is complete annotation for twenty classes: i.e. all images are annotated with bounding boxes for every instance of the twenty classes for the classification and detection.

The *ImageNet* is an image database organized according to the WordNet hierarchy (currently only nouns), in which each node of the hierarchy is depicted by 14,197,122-labelled high-resolution images organized by means of 21841 indexes and belonging to roughly 22, 000 categories. Currently, we have an average of over five hundred images per node [189], [190].

The *Caltech-256 Image Set* is an image database released in 2006 consisting of 257 categories of images, created based on the Caltech-101 image set. It contains 30608 pictures in total, with 80 to 824 homogeneous pictures per category [191], [192].

The *Oxford Buildings Dataset* consists of 5062 high resolution (1024×768) images collected from "Flickr" by searching for particular Oxford landmarks [193], [194]. The collection has been manually annotated to generate a comprehensive ground truth for 11 different landmarks, each represented by 5 possible queries. The images are presented in different scales, viewpoints and lighting conditions.

The *Paris Dataset* consists of 6412 images collected from Flickr by searching for particular Paris landmarks [195], [196] and is analogous to the previous *Oxford Dataset.*

The PubFig83 and LFW datasets form a new benchmark dataset for open-universe face identification [197], [198]. Based on the realistic scenarios of an automatic search for people in web photos, or tagging friends and family in personal photo albums, the purpose of the dataset is to allow algorithms to find and identify some individuals while ignoring all the others as background, or distractor faces. This mimics many real-world applications where face recognition needs to ignore many background faces that appear in photos, but are not relevant to the user. PubFig83+LFW has 13,002 faces representing 83 individuals from PubFig83, divided into 2/3 training (8720 faces) and 1/3 testing set (4282 faces). From LFW, 12,066 faces representing over 5000 images are used as a distractor set.

Another possibility is Chabot - the image collection of the Department of Water Resources [17]) in California that is available without charge for non-commercial use from UC Berkeley. This DB is relatively large (more than 25,000 images), but has only a limited number of different subjects. No relevance judgments are currently available for this DB.

7.4 The Inner Structure of the Hybrid Semantic System Database

For our purpose, of the many databases existing on the market, we selected Oracle DB version 10g. We based our decision on the fact that Oracle DBMS deals with very large amounts of data, including multimedia data, as well as GIS data, which is very important with regards to our application.

We decided to prepare our own DB for two reasons: (i) when the research began (in 2005) there were few DBs containing buildings which were then at the centre of our attention and (ii) some existing benchmarking databases offered separate objects (like the Corel DB) which were insufficient for our complex search engine concept. At present, our DB contains more than 10 000 classified objects.

All project stages of our DB were carried out in Oracle Designer, version 6i. We used the entity-relationship modeller to generate all schemas. The end-product of the modelling process was an entity-relationship diagram (ERD), originally proposed by Pin-Shan Chen in 1976 [199]. In a modern form, an entity-relationship diagram (ERD) is a data model or diagram used to describe conceptual data models by providing graphical notations which document entities, their relationships, and the constraints that bind them. For our purpose, we do not introduce the whole entity terminology connected with entity types, it only has to be emphasized that herein an object is a graphical object understood as a fragment of an image obtained as a result of segmentation (not in the IT meaning).

Having transformed the entity-relationships diagram by means of the DB designer, we obtained the database server model which is presented in Fig. 7.2. In the tables we can also see ID numbers and foreign keys which the Oracle transformer added automatically. The DB discussed here has been generated and provided with data calculated by Matlab for this purpose.

The requirements analysis, which described information needed as a preliminary step in the design of a database, i.e. all input data generated by the image component segment, classification block and some preliminary information, such as a pattern library, had been known in advance [200], [201].

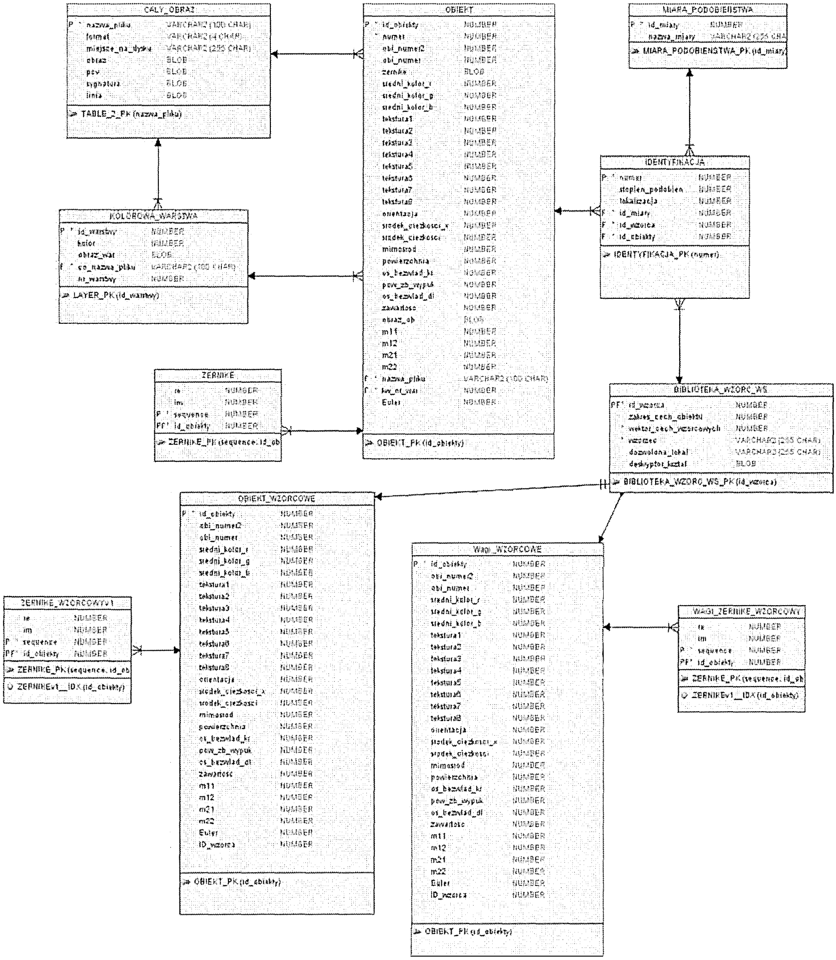

Fig. 7.2 The database server model which supports our CBIR system.

Information in tables is organized functionally according to the system model. It means that it reflexes the system's inner structure which is presented in Fig. 9.11. Each table stores data from one system's functional block. Thus the table titled FULL IMAGE consists of full information about the whole image, for example, its file name, file location, image as such, i.e. the BLOB with pixels, PCV, image signature and line structure which represents global information in our system. The COLOUR_LAYER and OBJECT tables consist of the information on the colour layers and low-level object data and link directly with the IMAGE table. The OBJECT table is the most capacious one because it compares object feature vectors and object images. Object classification is collected in the IDENTIFICATION table based on the information saved in the similarity measurement table and the pattern library table. The data from the pattern object table and weights for pattern objects power the pattern library table.

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