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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

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1 Introduction

Humans are primarily visual creatures because 79% of the information we receive about the environment is sight-related. In the modern world image serves different functions and purposes, for instance, informative, hortatory, recreational and aesthetic. Therefore, image has become a research area of many scientific domains, from arts, physiology, psychology, through education, information technology (IT), up to marketing and communication science.

1.1 From Retrieval to CBIR

Knowledge retrieval is an area of modern research that develops extremely dynamically. For thousands of years people have collected and stored their information in written form in different libraries. The advent of computers has not only replaced paper with magnetic data storage, but it has, in the first place, revolutionized the manner of perceiving and retrieving information.

As we all know, the first computers processed only numerical data and, generally, statistical methods were used for data retrieval, but in the next step, textual data were introduced and in order to effectively retrieve texts several text-based search engines were built. As a matter of fact, these engines were able to successfully find documents, without understanding the content. Usually, all the user had to do was to write a low-level description of what document they were looking for.

The more you have, the more you want and the modern user wanted to include images in his document. We can perceive images by sight and process them in our mind almost immediately, at the same time identifying their source. Ever since we learnt to record images, we have been collecting different sets of images that we need to browse and occasionally retrieve.

The problem that arises here is that for computers can only analyse a physical structure of an image, for example, a set of pixels in a grey scale or in colours. The user first adds proper names for image files. Second, the longer text annotations are attributed to images. But we must remember that whereas the text is man's creation, a typical image is a mere/simply replica/duplicate of what man has seen since his birth, the latter being relatively harder to describe precisely.

In a situation when text annotations are available, we can directly use the keywords for image search. In fact, in many situations text annotations do not exist or they are incomplete and then we have to refer to content-based retrieval methods.

The story of retrieval goes much further: through sound, video and information up to knowledge retrieval. The data-information-knowledge-wisdom hierarchy **[1]** is used in information sciences to describe different levels of abstraction in human centred information processing. However, the question is how to teach a machine to organize data in such a way that information, knowledge and wisdom retrieval can be possible. The answer is: to analyse the content.

1.2 A Need for an Effective and Efficient Search Engine and GUI

The reason why there is a distinction between text and image analysis is the fact that what we can see is hard to interpret even for a human. However, scientists have responded to the challenge, even though human recognition of images is still an open problem.

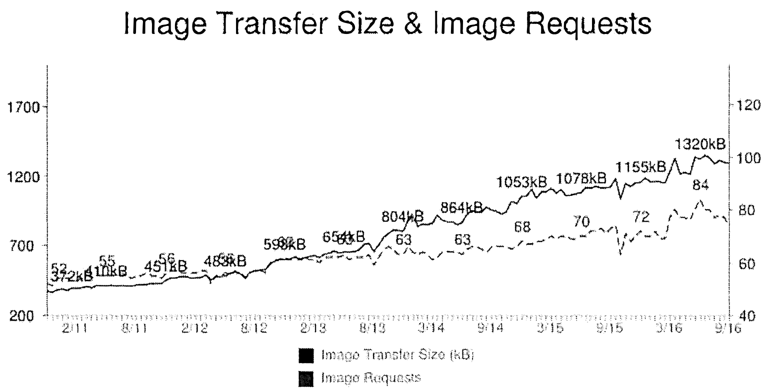

Fig. 1.1 This chart from [2] shows the average number of image requests and the total image bytes over the last five years.

Fig. 1.1 illustrates the image transfer and requests, spanning five years from 2011 to 2016. What can be noticed is that the number of images has gone up slightly, but the real total image size, and the resulting data transfer have grown dramatically.

Why do we use images so willingly? First of all, images carry information in a more concise form than a text. So nowadays, when the majority of people possess some form of digital camera for everyday use, it is easier to illustrate nearly everything with photos and to upload them to the Net.

In this situation, the fundamental open problem of image understanding arises. In order to solve it, we dramatically need a machine aid in finding a proper image in this visual deluge. Unfortunately, the algorithms so far have failed to accurately relate to the high-level concept, or the semantics of an image. Since machines deal with low-level features extracted from image pixels, they provide only a numerical description of images but with a wide gap in comparison to the human interpretation of the same image. This gap between the richness of high-level human perception and low-level machine descriptions is known as the 'semantic gap'. The user looks for semantic similarity, but the database can only provide similar images by digital processing. The problem with these algorithms is their reliance on visual similarity in judging semantic similarity. Moreover, semantic similarity is a highly subjective measure.

In this context, the development of effective and efficient content-based image retrieval systems is absolutely necessary. Nevertheless, the semantic gap between image properties and object properties broadly limits retrieval efficiency. This means that state-of-the-art systems, first of all, should offer to the user the possibility to put a clear query, optionally in textual or graphical form and later provide the answer containing semantically similar images. In traditional, alpha-numeric DBs the system of queries has been highly developed, whereas for the image retrieval a content query has not met up to users' expectations. It stems from the fact that content-based searches have important distinctions compared to traditional searches. It is the reason why graphical user interfaces (GUIs) have a different structure in order to reflect the engine's inner data organization. And again, the easier and more intuitive the query interface, the more effective the user's request and the more efficient retrieval result.

There are two most popular approaches to query formulation: typing some key words describing the image and setting an example image as a query [3], [4], [5]. The most infrequent strategy is the preparation of queries by drawing several objects with certain properties, like colour, texture, shape, size and location. In most cases, a rough sketch is sufficient. Query by drawing is not popular, perhaps because most users are rather poor at graphic design [6].

Some applications, for instance medical CBIR systems, allow selecting subregions of interest as part of a query [7]. The user chooses properties of these ROIs, such as shape or texture, to complete the query definition [8].

Chronologically speaking, the first systems used annotations [9], [10], which was an advantage, but this method did not take into account images described in an inaccurate way. Such systems are still used in news agency databases. Next, query by example (QBE) [11], [12] appeared which allows the user to formulate a query by providing an example image. The system converts the example image into an internal representation of features. At present, most systems use this kind of query, but their drawback is the fact that the user first has to find an image which he wants to use as a query. In some systems, like police collections of mug shots or finger-prints, applying a QBE is obvious. Nevertheless, in some situations the most difficult task is to find this one proper image to give it to the system as a query by example.

However, there are some other ways, for instance, systems have appeared recently with a composed query introduced by GUI where the user can comprise his query from selected segments or patches [13].

With this objective in mind we set out to write this book.

1.3 Outline of the Book

The purpose of this book is, first of all, to present to the public the main problems of image retrieval and the-state-of-the-art of content-based image retrieval in particular. It is described based on a wide survey of selected methods indispensable to follow the construction of a particular CBIR system.

The target readers of this book will be mainly researchers and engineers, as well as graduate students working in various fields linked to image processing and analysis, such as computer vision, pattern recognition and, broadly speaking, multimedia and artificial intelligence (AI).

For this reason, this book is not intended to describe in detail all the aspects and systems that have appeared so far. Our aim is to focus on the classification of the main concepts of image retrieval with its numerous stages and many variants of different techniques which have already been implemented. This work does not cover video retrieval, as it uses quite a different search method which could be the subject of another voluminous book.

At the beginning, we introduce an overview of data, information and knowledge retrieval as an important branch of modern research.

In Chapter 2, first, the main problems with image perception are presented. The plethora of kinds of images results in building many systems of different types and presentation of some novel solutions in the Hybrid Semantic System (HSS) which have been carried out in the Systems Research Institute of Polish Academy of Sciences.

Next, the abundance of developed CBIR systems is classified according to a variety of aspects considered during the process of the systems' creation.

This chapter ends with a description of the concept of the HSS and the motivation behind its construction.

Chapter 3 commences with the issue of image representation. Next, we consider the low-level image descriptors, such as colour, texture, edge and shape. In the Hybrid Semantic System (HSS), each of the previously mentioned descriptors has been used and we emphasize the novelty of particular elements of each descriptor application, for example, the texture description is based on a 2D wavelet discrete analysis.

Further on, the standardization efforts are described, especially the MPEG-7. Later, the local features are compared with the global ones because we need they all to fully analyse an image. Global features are generally represented by different kinds of histograms which are compared with each other.

This chapter finishes with the notion of signature based on the features as such. The signature here is understood as a function which describes the whole image in a summary way.

In Chapter 4 we detect the semantic elements of an image, namely objects. In the HSS we select image segments based on our colour algorithm which offers more segmentation precision than other algorithms. We end this chapter with a detailed description of data representation in the HSS.

In Chapter 5 we present some most commonly used classifiers in the context of earlier extracted segment recognition. First we list metrics employed in vector comparison in order to define object similarity or dissimilarity, then we apply decision trees, Naïve Bayes classifier, support vector machine, and fuzzy rule-based classifier (FRBC). In the second half of this chapter, we describe the two stage classification applied in our HSS. The relevant new element is the use of the FRBC as a second decisive step in resolving ambiguities which could have appeared in the first step of classification. In this situation many problems, arising from the fact that real/crisp data have been used, need to be solved.

The last, but not least, novel idea in this chapter is the definition of spatial relationship between graphical objects in an image. We introduced algorithm describing points and angles location on the plain based on the principal component analysis (PCA). As a result, later we use three main components of PCA for finding similarities between images.

In Chapter 6 we develop the notion signature which has been introduced earlier to the Signature Quadratic Form Distance. Next, we describe the novel asymmetrical approach to the signature similarity applied in our HSS.

Chapter 7 is devoted to image collections and the inner structure of the DB which store all data of our HSS. Additionally, we expose the problem of benchmarking CBIR systems.

Chapter 8 presents the graphical user interface, beginning from the concept of queries up to our, specially designed for graphical query, interface.

Chapter 9 describes the most important elements – search engines of systems for the nine latest designed engines. In this context, we present our state-of-the-art HSS search engine which specially consists of three stages for semantic searching. At the end of the search engine description we present the matching result in comparison to other academic search engines and the Google one. Our matchings are specially focussed on the semantic search in order to overcome the gap which results fromin the computer approach to image analysis.

Chapter 10 describes the wide spectrum of CBIR applications, as well as the users of such systems.

Chapter 11 closes and sums up the book by presenting the future challenges and states the open problems which face the CBIR systems.

Each chapter is richly illustrated and the extensive references are provided.

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