Chapter XVIII

Case Study: Cairo - A Distributed Image Retrieval System for Cluster Architectures

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Cairo is a distributed, cluster-based image retrieval system that provides a high-quality, object-based image analysis and search. The state-of-the-art retrieval approach, which compares entire images, is extended by an exhaustive search in all image sections for the occurrence of selected regions of interest. The large computational effort requires the use of parallel architectures in order to maintain reasonable system response times.

The goal of this chapter is to give an overview of the different techniques required for distributed image retrieval, such as querying mechanisms and operations for image analysis and comparison, related aspects of parallel processing, scheduling, and data placement. The proposed architecture, Cairo, combines all these aspects and offers one possible design for a user-friendly, flexible, efficient, and distributed image database. The global system structure, the design of the individual modules, the internal communication, and typical use cases are outlined in the main part of this chapter.

INTRODUCTION

The need for a suitable representation, explanation, and presentation of information is found in nearly every area of our day-to-day life – in business and educational applications, in science and entertainment. Documents are usually composed of a number of different media instances, which convey information segments in the most suitable manner and help in

understanding of the depicted knowledge. The contained media, also known as multimedia objects, are usually divided into:

- **Time invariant (*discrete, static*) media**: These are single elements or an element continuum without a time component. Text, graphics, and images belong to this class.
- **Time variant (*continuous, dynamic*) media**: The value of media changes in time and depends on the content as well as on the time of its occurrence. Video, audio, and animation fulfill this requirement.

The memory demands of multimedia objects surpass the requirements of conventional, text-based documents by orders of magnitude. For example, a PAL frame with a resolution of 768 x 576 pixels needs 1.26 MBytes memory, which corresponds to 630 ASCII coded text pages. A single second of audio in CD quality requires approximately 180 KBytes; a full-screen, full-motion, color video sequence of the same length requires nearly 112 MBytes of memory. The compression with algorithms, such as JPEG for images or MPEG for video sequences, reduces these requirements to approximately 30 MBytes/s for the video stream and 8 KBytes/s for the audio sequence (Davies & Nicol, 1991).

The bandwidth requirements of multimedia objects are closely related to their memory size. The most important parameters for transmitting continuous multimedia objects are maximum and average packet delay, packet delay jitter, packet loss probability, and on-time reliability. Moreover, conditions regarding user interaction and presentation mode for the media have to be considered, for example:

- **Interactive control**: Users are allowed to change attributes, interrupt and subsequently continue the presentation of the current media at any time.
- **Quality of Service (QoS)**: Collection of requirements for the recording and playing of continuous multimedia objects.
- **Synchronisation constraints**: Define the timing and the spatial order of independent media objects, as well as their content relations.
- **Dynamic adaptation** to the currently available resources.

These requirements and the increasing multimedia data production create a need for steady improvements of all components of a multimedia system. Centralized solutions are usually not powerful enough for dealing with a large number of users, queries, and with rapidly growing data sets. Thus, the given QoS demands cannot be fulfilled any more, resulting in restricted system functionality. Therefore, improved computer architectures, memory organizations, networks, and new methods for organizing, managing, and retrieving multimedia data have to be integrated in modern information systems. This chapter presents this combination using a specific reference model for a cluster-based system for image retrieval, called Cairo (*Cluster Architecture for Image Retrieval and Organization*). The requirements and the trade-offs necessary, as well as their impact on the design process, are highlighted. Most of the methods and design principles presented can also be used for general multimedia data.

The chapter is organized as follows: The next section offers an introduction of the basic principles of parallel and distributed multimedia applications. Subsequently, the processing steps of a multimedia retrieval are depicted by using an image database as an example. The main part of this chapter considers the system model used in the design of Cairo. Here, the structure and the functionality of the included modules are detailed. In the last section of this chapter a description of characteristic use cases such as data insertion and retrieval is provided.

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