Information Sciences 192 (2012) 71–81

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

An application of swarm intelligence to distributed image retrieval

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ARTICLE INFO

Article history:
Received 14 August 2009
Received in revised form 16 December 2009
Accepted 8 March 2010
Available online 21 March 2010

Keywords:
Distributed information retrieval
Content based image retrieval
Multi-agents system
Ant colony optimization

ABSTRACT

In this article, we introduce an application of swarm intelligence to distributed visual information retrieval distributed over networks. Based on the relevance feedback scheme, we use ant-like agents to crawl the network and to retrieve relevant images. Agents movements are influenced by markers stored on the hosts. These markers are reinforced to match the distribution of relevant images over the network. We tackle the use of the information gathered during previous search sessions. In order to match the different categories available on the network, we use several markers. Sessions searching for the same category will thus use the same makers. The system involves three learning problems: the selection of relevant markers regarding the searched category, the reinforcement of these markers and the learning of the relevance function. All of these problems are based on the relevance feedback loop. We test our system on a custom network hosting images taken from the well known *TrecVid* dataset. Our system shows a high improvement over classical content based image retrieval systems which do not use previous sessions information.

1. Introduction

The exponential growth of multimedia contents (*i.e.* images, videos or music) available on the Internet raises the question of the adaptability of searching tools to this highly distributed context. This is even more crucial when considering p2p networks: no centralized structure can gather all the information in the manner of classical web search engine. However, the decentralized nature of the production of multimedia content can have numerous advantages, such as the possibility of sharing computational and storage resources, and the absence of data replication (and the questions of updating). To benefit from such distributed structures, searching tools must be able to find the good location of relevant documents, *e.g.* to route the query among the peers correctly. This question has been widely studied in the p2p literature [20].

The question of image retrieval in this distributed context has been studied recently [5,17]. Classically, in content based image retrieval (*CBIR*), visual features are extracted from the images and then compiled into an index or signature [22]. To perform the retrieval, a similarity function is computed to compare the index of the query to those of the collection. A ranking of the results is produced according to the similarity and shown to the users. To further improve the quality of the retrieval, an interaction with the user, called *relevance feedback* [23,13], can be added. The user labels a fraction of the results, and the similarity function is updated consequently. Some machine learning techniques have been widely used in this case, and have shown very good improvements. Distributed *CBIR* is more challenging. In order to be efficient, distributed systems shall include the relevance feedback scheme but also a network exploration strategy [5]. Given a network of computers hosting images, systems must find the locations of relevant images, before any similarity learning. We have previously proposed such a *CBIR* extension to distributed sources based on biologically inspired multi-agents systems. In this

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doi:10.1016/j.ins.2010.03.003

system, the ant-like behavior of the agents leads to the optimization of the source selection in which we perform the retrieval, with successful results [16].

The main purpose of this paper is to deal with long-term memory of network based system for information retrieval. Indeed, the main drawback of classical information retrieval (*IR*) systems, is their absence of memory regarding previous queries. In the case of a widely used and highly distributed system, we dispose of numerous search sessions. The challenge is to be able to re-use the knowledge brought by users in past search sessions to improve future sessions. In this context, the improvement can be done in two different ways: either by updating the similarity function according to the previous sessions, or by improving the selection of the images collections regarding the locations previously learned. In this paper, we undertake to improve the source selection stage by using the relevance feedback of past sessions only. This leads to a threefold learning problem: learning paths during the search session, merging paths learnt during previous search sessions, and learning the similarity function. We introduce a multiple-layered architecture to handle the three learning problems in a unified framework. We use an ant-like multi-agents system that learns the paths leading to relevant images collections regarding the searched category.

In the next section, we introduce a biologically inspired multi-agents systems (*MAS*) for information retrieval. In Section 3, we describe how the system works for a single session, which we call our "*intra-session*" learning strategy. The use of several previous sessions to further improve the system, which is called the "*inter-sessions*" learning strategy, is shown in Section 4. We then present extensive experiments done on an *ad hoc* network, using the *TrecVid'05* image dataset.

2. Multi-agents systems for information retrieval

Distributed information retrieval (*IR*) systems need to perform three tasks [3], namely:

1. Selecting the collections in which performing the search.
2. Processing the documents on the selected collections.
3. Merging the results from the selected collections.

The second step is well known, as it does not differ from classical *IR*. The third step might contain difficulties, especially when the measure used to produce the results on each source are not directly comparable. This is often the case in distributed *CBIR* where different collections may not use the same indexing techniques [1]. However, the first step is, to our minds, the more challenging. The ever growing number of sources forbids the exhaustive propagation of the query to each collection: Relevant sources must be identified so as to optimize the use of available resources. Typical problems involve optimal routing to minimize bandwidth waste and correct distribution of the processing tasks among the computational resources.

Multi-agents system have proved to be highly efficient for these tasks specific to distributed systems. Multi-agents systems are often used to parallel processes or to add robustness (by adding redundancy). In our work, we focus on *mobile agents*, a particular subset of *MAS* with nice properties for information retrieval. Mobile agents are autonomous computing software with the ability to migrate its executable code from one peer of the network to another and to continue its execution there [14]. Mobiles agents have been the focus of many researches in the late 1990s. There are good reasons to use mobile agents for information retrieval [15], such as the absence of a global structure in the network, the natural discovery of new collections, and the automatic paralleling of the processing. Recently, search engines based on mobile agents have been built [19,18,2,11].

To further improve these agent based search engine, the next step is the introduction of swarm intelligence algorithms. *Ant colony optimization* [9] is an optimization strategy inspired by the behavior of ants while foraging. By modifying the environment, agents contribute to a collaborative solving of the problem [8]. It has been shown to be efficient in various optimization problems like *quadratic assignment problem*, *traveling salesman problem* [10], with applications to network routing, for instance [4]. In the case of information retrieval, many agents try to collectively find relevant documents during a search session leading to a better routing of the query, like in [18]. As there are many users of the network, the interaction of different sets of session related agents shall lead to further improvement.

In the specific case of distributed *CBIR* based on relevance feedback scheme, the three steps defined at the beginning of this section have to be done at each round. We expect the use of *ACO* like algorithm to be able to boost the source selection step by merging the information gathered by many agents (owned by several users) regarding the relevant hosts.

3. Intra-session learning strategy

In the hereby section, we recall the first system addressing distributed *CBIR* we developed [16]. The design is based on the relevance feedback scheme of classical *CBIR* tools, with the use of ant-like agents to handle the step 1 of distributed retrieval.

3.1. Selection strategy

To address the problem of the selection of sources, we introduce the *relevance* r_i of a host i, which is the number of relevant images it contains over the number of images in its collection. Thus, a collection with only relevant images has a relevance of 1, whereas a collection with no relevant image has a relevance of 0. The strategy we proposed consists in