Distributed Image Indexing and Retrieval with Mobile Agents

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1 Context and Current Approaches

At present, the de-facto platform for providing contents in the Internet is the World Wide Web. A technology, which is now emerging on the Web, is *content-based retrieval* (CBR). A content-based query matches examples or prototypes to known instances of a certain media type based on a measure of similarity. For efficiency, similarity measures are frequently computed on sets of discriminant features (so-called *feature vectors*) being extracted a-priori from the stored media.

A number of CBR systems have already been developed. Hardly any article related to CBR fails to acknowledge IBM's QBIC system [6] and MIT's Photobook [8]. Both operate on images available locally, though. Smith et al. [12, 13] developed a CBR system for the World Wide Web. Scarloff et al. [11] developed a content-based image query system including a *gatherer* collecting images from the Web. Beigi et al. [2] already applied the principle of meta-searching to a number of available image search engines.

2 Drawbacks

Although a start has been made, the present approaches towards supporting a market for digital images suffer from a number of disadvantages:

Image indexing is centralized; all images have to be transfered across the network to some indexing process, or a group of processes distributed over a set of hosts. Image gatherers such as the one presented by Sclaroff et al. [11] request images using HTTP requests. Robot etiquette protocols mandate that a site must not be flooded with requests. Therefor, the gatherer needs to wait between requests, which increases the time required for requesting and receiving an image. This time is identified as a performance bottleneck. The introduction of new CBR models, such as models applying domain-specific knowledge, remains inflexible. As a rule of thumb, systems applying domain-specific knowledge achieve higher precision at the price of being applicable only to a focused domain of images [8]. Once, images are transferred to a remote indexing process, all control on the distribution of the image data is lost.

In this article, we address these problems by proposing an alternative architecture and model for distributed indexation and searching of images (the essentials are outlined in Figures 1 and 2) that combines CBR, mobile agent technology [17, 16, 9], and digital watermarking (see for instance [1]).

3 CBR with Mobile Agents

Mobile agents [10, 9, 16, 17] push the flexibility of distributed systems to their limits since not only computations are dynamically distributed but also the code that performs them. A number of mobile agent systems are in existence at present; basic information on about 60 such systems (including ours) was collected in the run-up to the ASA/MA'99 Conference that took place beginning of October in Palm Springs, USA.

We anticipate image brokers running a CBR service. This service is queried using example images or feature vectors already extracted from them. The CBR service returns a list of image descriptors of images matching the query in the order of similarity.

Each image descriptor consists at least of a thumbnail, the image identifier of that image (unique within the domain of the image provider), a measure of "similarity" to the original query image, and the URL of the provider's agent server from which the image can be retrieved. The images themselves must be retrieved from the providers. This ensures that providers may identify customers and may apply digital watermarks to retrieved images.

Image indexation is done with mobile agents, which transport the CBR feature vector extraction and collection algorithm to the servers of image providers. Indexing agents may compute and collect indexes of multiple image archives, which are sent back and merged to the broker's main index. This model is illustrated in Figure 1; triangles stand for agents. As an alternative, the agents may offer CBR services directly from the image provider's host, which completely eliminates the need to transfer indexes. In this case, brokers provide a directory service from which the locations of the index agents can be retrieved by search agents (see Figure 2 for an illustration of this model).

Content providers run an image service that returns image data based on a ID. While retrieving thumbnails is free, retrieving full images is subject to access control. In accordance to agreements between brokers and providers, index agents are authorised to read full images for the purpose of indexing. Search agents are allowed to retrieve full images only if appropriate licenses were purchased beforehand.

The mobile agent approach can complement Web-based approaches. We developed a mobile agent platform featuring a service that allows mobile agents to register Servlets at a HTTP Daemon agent (which can in principle be mobile itself). Agents may thus communicate results to human users through ordinary browsers.

4 Security Considerations

Providing adequate security is crucial for the applicability of the model presented in this article. The security of mobile agents in general plays an important role, since agents may threaten hosting machines (denial-of-service, viruses, covert channels) and other agents (privacy, integrity). On the other hand, hosts may deceive or defraud visiting agents. This is particularly critical if agents are to negotiate license terms on behalf or their owners.

Providers may also be tempted to peek on images collected by visiting agents from competitors, or to reduce the quality of such images, or to remove them altogether. In summary:

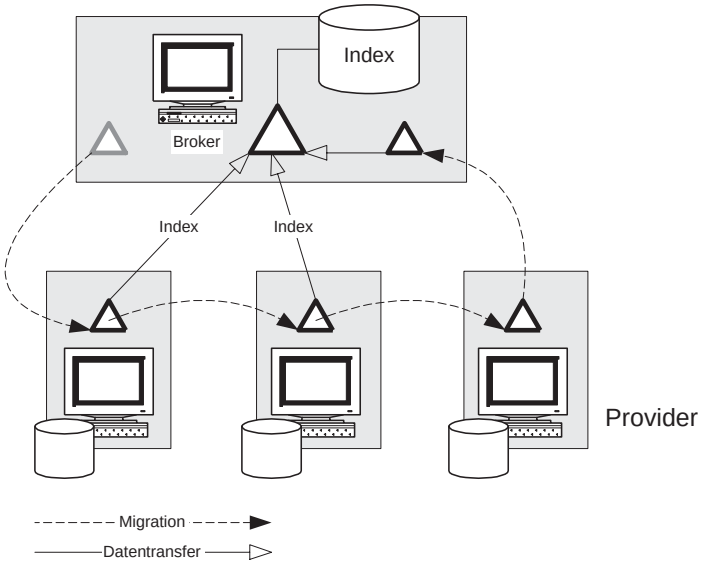

Fig. 1. The model with a centralized index.

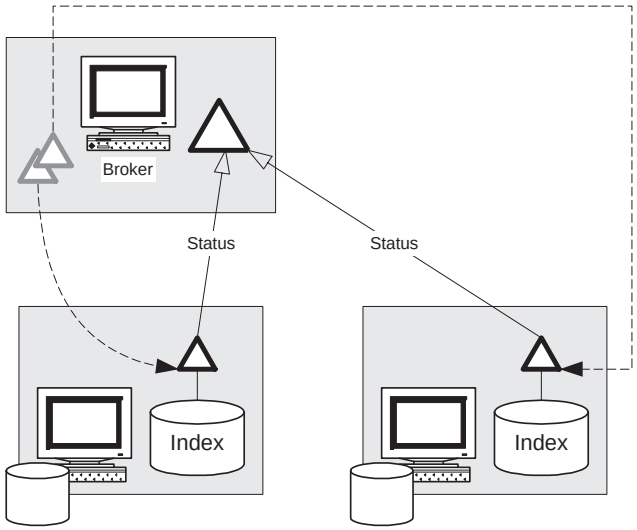

Fig. 2. The distributed index model.

1. agents must be protected against malicious hosts,
2. hosts must be protected against malicious agents,
3. agents must be protected against other agents,
4. both agents and hosts must be protected against the rest of the world.

Item 4 can be dealt with in ways known from any Client/Server system operated in the Internet, for instance by using transport layer security and putting proper security policies into effect. However, mobile agents invalidate certain assumptions on which Client/Server security is based, as described nicely by David Chess [4].

Item 1 is generally recognised as being particularly challenging. Despite advances in conceptual mobile agent security issues [14, 15], few agent systems actually seem to offer security mechanisms beyond transport layer security. For this reason we develop a mobile agent server that we use to explore practical security issues for mobile agents. The title of this server – *Secure Mobile Agents* (SeMoA) – was chosen to reflect this focus. The SeMoA server is the basis of our CBR application.

The CBR application itself imposes further security requirements, one of the most prominent ones being the illicit export of image data. Belmon et al. [3] propose to compensate potential losses due to covert channels by charging agents with the anticipated value, regardless whether agents use the channel or not; an approach that we think is not user-friendly and acceptable. We still favour tracing of digital watermarks as the mechanism of choice.

Delegating negotiation to agents, be they mobile or static, requires on one hand sound technical security, and on the other hand a proper legal framework. Our goal is to investigate and thrive to solve security implications of the described framework involving indexation, search, purchase and payment of image (licenses) with mobile agents (see for instance [15] for a good coverage of mobile agent security issues).

5 Conclusions

The mobile agent approach has a number of advantages. Multiple (complementary) indexing and retrieval mechanisms are be supported in a single framework; such mechanisms are easily replaceable as the field of CBR evolves towards more robust and applicable mechanisms. Software distribution, installation and removal is easy and painless. Image indexing is decentralized. It is computed “near” the image database by index agents migrating to the agent servers of image providers. Images must not be transported across networks for index generation any more. Retrieved images can be “personalized” by watermarking them with the identity of the purchaser.

Presently, we are implementing a prototype based on the (yet unpublished) SeMoA (Secure Mobile Agents) platform and a watermarking system developed by the *Institut für Graphische Datenverarbeitung in Darmstadt* [5], and a content based retrieval mechanism based on color coherence vectors [7].

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