DISTRIBUTED MPEG-7 IMAGE INDEXING USING SMALL WORLD USER AGENTS

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ABSTRACT

An open, peer-to-peer architecture for performing distributed image indexing and retrieval is proposed. The system employs a sociological model of human acquaintance networks (small world theory) and concepts derived from the nature of the World Wide Web. Retrieval is performed using agents, and a node hopping algorithm is employed that exploits node referrals established from descriptor data stored locally by each node. A general framework for this *Small World Image Miner* (SWIM) is presented along with a realization using MPEG-7 Color Structure descriptor data for 2400 images. Results related to search agent path length and network node indegree are presented.

1. INTRODUCTION

The field of multimedia indexing has blossomed in many ways since QBIC [1] originally blazed the trail for the many researchers which followed. Despite some systems [2, 3] having addressed both distributed and peer-to-peer ideas [4, 5], the convenience of centralized techniques for indexing image descriptions, a central descriptor index is still almost always assumed. To address this, and alternative approach to centralized image indexes is proposed using a distributed rationale. Unlike centralized approaches, distributed techniques exhibit graceful index degradation (and thus survivability) at the cost of increased overhead and complexity. Organization of the paper is as follows. Section 2 discusses the rationale and model used for the *Small World Image Miner*'s distributed index, while Section 2.1 presents the SWIM system, network growth, and retrieval techniques used for the experiments provided in Section 3. The paper ends with conclusions and future work in Section 4.

2. SMALL WORLD DISTRIBUTED INDEXING

The phrase "*it's a small world*" has proven quite truthful and nearly everyone is connected via an intricate series of complex relationships. Early studies on such '*small world*' acquaintance networks were performed by Pool and Kochen [7] (among others), yet it was Milgram who first put social network theory into action and arrived at the conclusion that the typical number of hops or *degrees of separation* between any two people was approximately equal to six [8]. More recently, small world theory has received renewed interest as a result of the work of Watts and Strogatz in their analysis of networks exhibiting the small world qualities of high *clustering* and low characteristic path length [9].

2.1. SWIM

A small world paradigm is employed here to perform distributed indexing of MPEG-7 data through the local storing of peer node description data. Although *any* descriptors could be used, MPEG-7 descriptors are employed here in order to agree with the ISO standard for still image description. The *Small World Image Miner* (SWIM) creates a directed small world network of images which are connected according to MPEG-7 descriptor similarities. This rationale is similar to the way in which World Wide Web pages exist on the Internet, where directed links typically point to additional pages with similar subject matter. In addition, the SWIM system attempts to mimic the way humans perform referrals and introductions between acquaintances. It is only because humans retain descriptions about the members of their acquaintances that they are able to make introductions between people who they believe are somehow similar (i.e., a decision is made on whether two acquaintances share common interests, backgrounds, etc.). Under this small world concept, images must become active elements within the index, storing descriptor data about their most similar peers as well as constantly interacting with new images and search agents by performing distance calculations and acting as referrers to new or more similar nodes. This system is different than the distributed approach used by *CHORD* [4] as no hash function is used for distributing and locating data, and searches are performed using a decision-based agent according to local node data descriptions. Although exhibits some similarity to the DISCOVIR system [3], SWIM permits multiple levels of MPEG-7 descriptor data, locally stores descriptor data at every node, and promotes searching through the exclusive use of directed links. In addition, unlike DISCOVIR, each peer in the SWIM framework is permitted to have its own distinct set of peer connections, and is not limited by peer connections that are dictated by its host computer. As shown

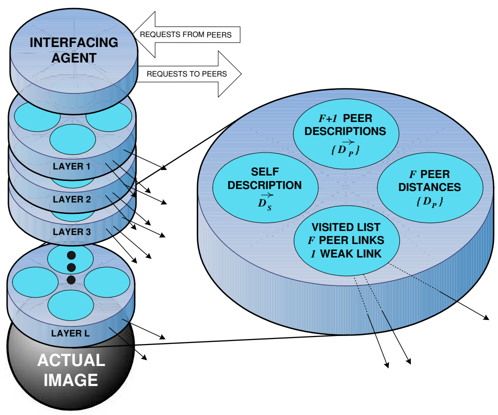


Fig. 1. In addition to actual pixel data, a *SWIMage* consists of a set description layers and an interfacing agent for communication between other nodes. Each description layer stores description data vectors as well as directed links to similar *SWIMages*.

in Figure 1, each *SWIMage* consists of an agent for providing interaction between other SWIM network elements, and multiple description layers locally storing self and peer MPEG-7 descriptor data as well as directed links to similar peer *SWIMages*.

Similar to the Newman-Watts model [10], a SWIM network consists of a regular lattice merged with what seems like a random graph. Each SWIM network layer, L_ℓ, establishes F directed nearest-neighbor links (friends) between vertices using an external distance measure D_ℓ in the creation of its *Similarity Graph*, $G_{S\ell}$. A single, directed *weak* link between successive nodes is used to generate the *Weak Graph*, G_W. These two components are illustrated in Figures 2(a) and (b).

The external distance measure employed establishes the peer set for each node, and must be appropriately chosen with respect to the descriptor at hand. With this concept in mind, the graph $G_{S\ell}$ can alternatively be thought of as a directed F-lattice within the layer's descriptor space, while G_W represents an incrementally grown graph which (assuming no broken links) serves the purpose of ensuring graph connectivity and allowing network search agents to jump out of tightly connected cliques [11]. It is important to mention here that since peer links are directed in nature, target

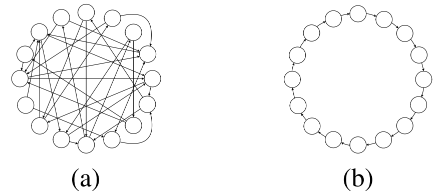


Fig. 2. A 16-node SWIM network. Connections are made (a) from each node to $F = 2$ friends according to an external similarity metric to create $G_{S\ell}$ and (b) between successive nodes to create G_W.

SWIMages do not store descriptor information about their referrers, but only about the images to which they link. This results in a fixed outdegree for each node of $F+1$ (F peers, plus one weak link). Furthermore, because directed links must start and end somewhere, the average indegree over all SWIMage nodes must necessarily be equal to the average outdegree. Yet, because there is no a priori knowledge about the images being indexed, the *actual* indegree of any given vertex cannot be predicted beyond the knowledge that it will have a minimum value of unity. It is for this purpose that a directed paradigm was chosen in order to keep fixed the amount of locally stored peer description data.

2.2. SWIM NETWORK GROWTH

To stay in line with the concept of a distributed index, it is imperative that the method used in establishing node connections be as de-centralized as possible. For achieving this, an incremental growth and indexing algorithm is employed by each SWIMage to both ensure connectivity among all SWIM elements, and make certain that each SWIMage has compared itself to all other peers. The assumptions of an existing SWIM network as well as the random introduction (insertion) of new SWIMages to established ones are made. This algorithm consists of two phases; an *introduction phase*, followed by an *exploratory phase*. The introduction phase involves communication between a new SWIMage j and an insertion (or introducing) SWIMage k, in which node j is passed node k's peer information and then incorporated into the weak graph G_W. The exploratory phase begins as nodes j and k perform mutual distance calculations on their respective descriptor vectors $\overrightarrow{D_k}$ and $\overrightarrow{D_j}$ to determine d_{kj}. The algorithm outlined in Figure 3 shows the steps taken by each newly introduced SWIMage. During each node visit, descriptor information is compared according to a given distance measure, and if necessary, exchanged descriptor data is locally stored by each SWIMage. Because only newly introduced SWIMages 'hop' from node to node, there is no need for existing elements to be informed of the existence of new ones; new SWIMages automatically find them by traversing the SWIM network.

LOOP (While j target queue != NULL)
SWIMage k passes friend list to j's target queue.
SWIMage k passes weak link w_k to j's target queue.
IF (SWIMage $j \ni G_W$)
SWIMages j and k swap weak links w_j and w_k.
(new SWIMages weakly link to themselves)
Both i and k calculate mutual distance d_{jk} (equal to d_{kj}).
IF ($d_{kj} < d_{k,F}$)
Node k appropriately inserts $f_{new} = (d_{kj}, j, \overrightarrow{D_j})$
into friend list and culls to F friends.
IF (SWIMage j has fewer than F friends)
Node j appropriately inserts $f_{new} = (d_{jk}, k, \overrightarrow{D_k})$
into friend list.
ELSE IF ($d_{jk} < d_{j,F}$)
Node j appropriately inserts $f_{new} = (d_{jk}, k, \overrightarrow{D_k})$
into friend list and culls to F friends.
Node j 'hops' to next node in it's target queue
(nodes to be visited).

Fig. 3. Algorithm for SWIM index growth.

2.3. SEARCH AND RETRIEVAL

The process of query-by-example retrieval is performed using a search agent. In a fashion similar to how new SWIMages are introduced into the small world network, search agents are inserted at a starting node, and then proceed to 'hop' to subsequent nodes. Each hop is determined by a local distance calculation performed between the agent's search criteria and the self and peer descriptor data stored by the currently visited SWIMage. Figure 4 outlines the retrieval algorithm used for performing query-by-example in a SWIM network. Using this approach, the retrieval agent

LOOP (While unvisited nodes exist)
FOR ($i = 0$ to $F + 1$)
Find d_i between query and friend i of current node.
IF (Peer i unseen)
Insert Peer i into retrieval list according to d_i.
Hop to next unvisited node with smallest distance.

Fig. 4. Algorithm for SWIM agent searching.

actively traverses links which exhibit the smallest distance from the search criteria. During search, the importance of the Weak Graph G_W becomes evident as it gives an agent the ability to jump out of a cyclical clique of nodes. Such cyclical cliques are problematic because they represent a case where a small subset of index images have F peer links which only point to each other. In addition, weak links also act as bridges to SWIMages that are unrelated to local data cliques in cases where node peers have descriptor data that is highly dissimilar to an agent's query.

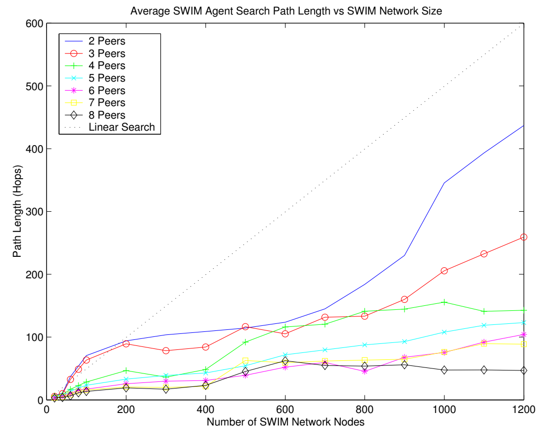
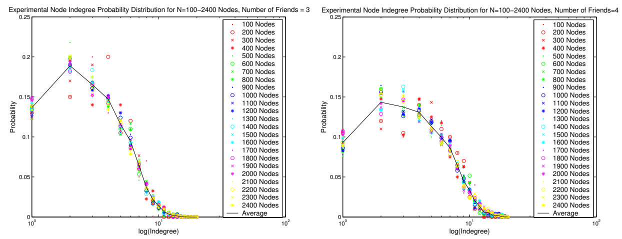


Fig. 5. Number of hops for search agent versus number of nodes N and number of friends F.

3. EXPERIMENTS

The concept of a small world distributed index was tested using a database of 2400 images. These images are analyzed using the ISO *eXperimentation Model* (XM) source code which generates binary MPEG-7 descriptors vectors. In the experimental analysis of the SWIM index discussed here, a single descriptor layer is employed using the 128-bit *Color Structure* descriptor. Of interest is the number of 'hops' required to find a desired image during query-by-example. To this end, the path length of a search agent is monitored while performing query-by-example on different SWIM networks of sizes $N = 20, 40, 60, 80, 100, 200, \ldots,$ 1000 nodes. For each value of N, an agent is inserted into the network from all possible nodes, and the number of hops required to find the desired image is recorded. This value is then averaged over N for different values of F. The retrieval agent's behavior is illustrated in Figure 5. Search path lengths are compared to a linear search which would require $\frac{N-1}{2}$ hops (searches) as in the case of a centralized index consisting of linearly connected image nodes. The path length observed for the search agent turns out to be greater than the actual graph diameter because of the fact that the search agent must make a single decision as to which *directed* peer link to traverse. Yet, the difference between the number of hops required under a linear search and the number of hops required in the SWIM network is very large for all values of F as N exceeds 200. This difference is more pronounced for larger values of F which implies a larger variety of links for a search agent to traverse from any given node, resulting in a greater chance of finding a SWIMage with descriptor data that is very close to the query. This improvement however comes at the cost



(a) (b)

Fig. 6. Measured distribution of SWIMage indegrees over $N = 100$ to $N = 2400$ nodes for (a) $F = 3$ and $F = 4$. The number of SWIMages which exhibit indegrees of unity decreases as the number of peers F increases, resulting in a reduced importance on the weakly connected graph G_W.

of increased local storage of peer description data for each SWIMage. The plot in Figure 6(a) illustrates an experimentally extracted distribution of SWIMage indegrees for three SWIMage peers (friends). Similar to the distribution expected by webpages exhibiting a directed link structure [12, 13], the indegree probabilities of the SWIM network show a power law distribution. The appreciable density associated with SWIMages having an indegree of unity implies that a large percentage of system nodes are only pointed to through the weak links of G_W. This further implies a need for the weak linking of nodes as they are introduced into the network; a need, which as illustrated by Figure 6(b), decreases as the number of peers F increases.

4. CONCLUSIONS

A distributed approach for the indexing of MPEG-7 descriptor data using a directed small world paradigm was presented. This system attempts to model certain aspects of human social behaviour as well as the structure of links on the Worldwide Web. The Small World Image Miner (SWIM) employs images which actively participate in a peer-to-peer network by locally storing MPEG-7 descriptor data of self-similar images. Each *SWIMage* links to its F most similar images in the network for providing referrals. Search agents are subsequently employed to traverse the SWIM network. The search agent 'hops' to SWIMage nodes deemed as 'more similar' based on referrals by individual nodes made via distance calculations between locally stored descriptions. Analysis of the path length of a search agent showed that for network sizes larger that 200 nodes, an equivalent linear network (e.g. directed 1-lattice only) requires more hops. An analysis of the indegrees of SWIM network nodes shows a power law relationship where a low (but non-negligible) number of SWIMages have extremely large indegrees, and an appreciable number have indegrees equal to unity. This gives credibility to the claim that the Weak Graph G_W is needed to ensure that images which are not pointed to by other images, are reachable by a finite path. Future work with SWIM involves both an investigation of examining retrieval performance behaviour upon the incorporation of a cost function for peer connections based on physical link quality, as well as experiments involving relevance feedback enabled search agents. Furthermore, in attempts to prevent the search agent from traversing all nodes during retrieval, a containment algorithm is being incorporated into to try and end searches early when an acceptable results set is acquired.

5. REFERENCES

[1] M. Flickner, et. al., "Query by image and video content: The QBIC system", *IEEE Computer*, pp. 23-32, September 1995.

[2] R. Brunelli, and O. Mich, "Compass: An image retrieval system for distributed databases", *Proc. ICME 2000*, pp. 145-148, Jul 30-Aug 2, 2000.

[3] S. Ka Cheung, et. al., "Bridging the P2P and WWW divide with DISCOVIR", *Proc of the 12th WWW Conference*, Budapest, Hungary, May 20-24, 2003.

[4] I. Stoica, et. al., "Chord: A scalable peer-to-peer lookup service for internet applications", *ACM SIGCOMM 2001*, pp. 149-160, San Deigo, Aug. 2001.

[5] I. Clarke, et. al., "Freenet: A distributed anonymous information storage and retrieval system", *Lecture Notes in Computer Science*, H. Federrath (ed.), vol. 2009, Springer-Verlag, Berlin, 2000.

[6] J.M. Martinez, R. Koenen, and F. Pereira, "MPEG-7: the generic multimedia content description standard, part 1", *IEEE Multimedia*, vol.9, no.2 , pp.78-87, April-June 2002.

[7] I. Pool, and M. Kochen, "Contacts and influence", *Social Networks*, vol.1, no.1, pp. 5-51, 1978.

[8] S. Milgram, "The small world problem", *Psychology Today*, vol. 2, pp. 60-67, 1967.

[9] D.J. Watts, and S.H. Strogatz, "Collective dynamics of 'small-world' networks", *Nature*, no. 393, pp. 440-442, 1998.

[10] M.E.J. Newman, and D.J. Watts, "Renormalization group analysis of the small-world network model", *Physics Letters A*, no. 263, pp. 341-346, 1999.

[11] M.S. Granovetter, "The strength of weak ties", *The American Journal of Sociology*, vol. 78, no. 6, pp. 1360-1380, May 1973.

[12] J.M. Kleinberg, et. al., "The web as a graph: Measurements, models and methods", *Lecture Notes in Computer Science*, T. Asano, et. al. (eds.), vol. 1627, Springer-Verlag, Berlin, 1999.

[13] M. Faloutsos, P. Faloutsos, and C. Faloutsos, "On power-law relationships of the internet topology", *Comp. Comm. Rev*, no. 29, pp. 251-262, 1999.