DESIGN OF A PARALLEL AND DISTRIBUTED WEB SEARCH ENGINE

S. ORLANDO[°], R. PEREGO[*], F. SILVESTRI[*•]

[°] *Dipartimento di Informatica, Universita Ca' Foscari, Venezia, Italy*

[*] *Istituto CNUCE-CNR, Pisa, Italy*

[•] *Dipartimento di Informatica, Universita di Pisa, Italy*

This paper describes the architecture of MOSE (*My Own Search Engine*), a *scalable* parallel and distributed engine for searching the web. MOSE was specifically designed to efficiently exploit affordable parallel architectures, such as clusters of workstations. Its modular and scalable architecture can be easily adjusted to fulfill the bandwidth requirements of the application at hand. Both *task-parallel* and *data-parallel* approaches are exploited within MOSE in order to increase the throughput and efficiently use communication, storing and computational resources. We used a collection of html documents as a benchmark and conducted preliminary experiments on a cluster of three SMP Linux PCs.

1 Introduction

Due to the explosion in the number of documents available online today, Web Search Engines (WSEs) have become the main means for initiating navigation and interaction with the Internet. Largest WSEs index today hundreds of millions of multi-lingual web pages containing millions of distinct terms. Although bigger is not necessarily better, people looking the web for unusual (and usual) information prefer to use the search engines with the largest web coverage. This forced main commercial WSEs to compete for increasing the indexes. Since the cost of indexing and searching grows with the size of the data, efficient algorithms and scalable architectures have to be exploited in order to manage enormous amount of information with high throughputs. Parallel processing thus become an enabling technology for efficiently searching and retrieving information from the web.

In this paper we present MOSE, a parallel and distributed WSE able to achieve high throughput by efficiently exploiting a low cost cluster of Linux SMPs. Its expansible architecture allows the system to be scaled with the size of the data collection and the throughput requirements. Most of our efforts were directed toward increasing *query processing* throughput. We can think of a WSE as a system with two inputs and one output. One input is the *stream* of queries submitted by users. The other input is the *read-only database*, which contains the index of the document collection. The WSE process each query of the stream by retrieving from the index the references to the l most relevant documents. Such set of l references is then put on the output stream. The main parallelization strategies for a WSE are thus:

> *Task parallel.* Since the various queries can be processed independently, we can consider query processing an *embarrassingly parallel* problem. We can thus exploit a *processor farm* structure with a mechanism to balance the load by scheduling the queries among a set of identical workers, each implementing a sequential WSE.
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> *Data parallel.* The input database is partitioned. Each query is processed in parallel by several data parallel tasks, each accessing a distinct partition of the database. Query processing is in this case slightly heavier than in the previous case. Each data parallel task has in fact to retrieve from its own partition the locally most relevant l references. The final output is obtained by combining these partial outputs, and by choosing the l references which globally result to be the most relevant.
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> *Task + Data parallel.* A combination of the above two strategies. We have a *processor farm*, whose workers are in turn parallelized using a *Data parallel* approach. The farming structure is used to balance the work among the parallel workers.

The modular architecture of MOSE allowed us to experiment all the three strategies above. The third parallelization strategy, which combines *Task* and *Data parallelism*, achieved the best performances due to a better exploitation of memory hierarchies.

The paper is organized as follow. Section 2 introduces WSE and Information Retrieval (IR) principles, and surveys related work. Section 3 describes MOSE components, discusses parallelism exploitation, and shows how MOSE modular and scalable architecture can be adjusted to fulfill bandwidth requirements. The encouraging experimental results obtained on a cluster of three Linux SMPs are shown in Section 4, while Section 5 draws some conclusions.

2 WSE and IR Principles

A typical WSE (see Figure 1) is composed of the *spidering* system, a set of Internet agents which in parallel visit the web and gather all the documents of interest, and by the IR core constituted by: (1) the *Indexer*, that builds the Index from the collection of gathered documents, and, (2) the *Query Analyzer*, that accepts user queries, searches the index for documents matching the query, and return the *references* to these documents in an understandable

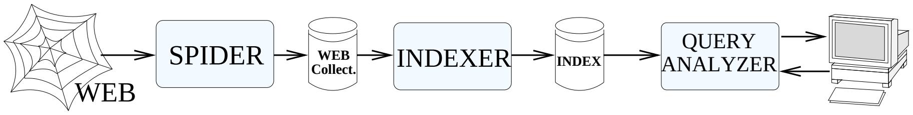


Figure 1. Typical organization of a WSE.

form. Query results are returned to users sorted by *rank*, a kind of relevance judgment that is an abstract concept largely linked to users taste. Ranking is performed on the basis of an IR model that allows to represent documents and queries, and to measure their similarity. In general, as the size of the indexed collection grows, a very high *precision* (i.e. number of relevant documents retrieved over the total number of documents retrieved) has to be preferred even at the expense of the *recall* parameter (i.e. number of relevant documents retrieved over the total number of relevant documents in the collection). In other words, since users usually only look at the first few tens of results, the relevance of these top results is more important than the total number of relevant documents retrieved. In order to grant high precision and computational efficiency, WSEs usually adopt a simple *Weighted Boolean* IR model enriched with highly effective ranking algorithms which consider the hyper-textual structure of web documents[1,2]. Moreover, due to its compactness, most WSEs adopt an *Inverted List* (IL) organization for the index. An IL stores the relations among a term and the documents that contain it. The two main components of an IL index are: (1) the *Lexicon*, a lexicographically ordered list of all the interesting terms contained in the collection, and, (2) the *Postings lists*, lists associated to each term t of the Lexicon containing the references to all the documents that contain t.

Many large-scale WSEs such as **Google**, **Inktomi** and **Fast**, exploit clusters of low-cost workstation for running their engines, but, unfortunately, very few papers regard WSE architecture design[1,3], since most developments were done within competitive companies which do not publish technical details. On the other hand, many researchers investigated parallel and/or distributed IR systems[4,5,6,7,8,9] focused on collections of homogeneous documents. Lin and Zhou[7] implemented a distributed IR system on a cluster of workstations, while Lu[8], simulated an interesting distributed IR system on a Terabyte collection, and investigated various distribution and replication strategies and their impact on retrieval efficiency and effectiveness.

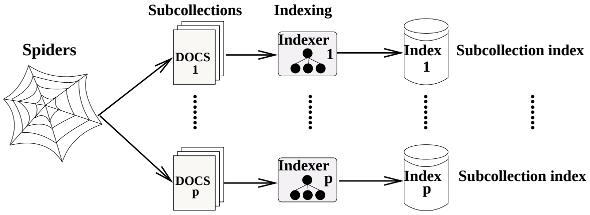


Figure 2. Indexing phase.

3 MOSE Structure

The IR core of MOSE is composed of the *Indexer* and the *Query Analyzer* (QA) modules. In this paper we only briefly surveys indexing issues, and focus our attention on the QA whose functionalities are carried out by two pools of parallel processes: *Query Brokers* (QBs) and *Local Searchers* (LSs). MOSE parallel and distributed implementation exploits a data-parallel technique known as *document partitioning* . The spidering phase returns p subcollections of documents with similar sizes. The subcollections are then indexed independently and concurrently by p parallel *Indexers* (see Figure 2). The result of the indexing phase is a set of p different indexes containing references to disjoint sets of documents. The p indexes are then taken in charge by a data-parallel QA whose task is to resolve user queries on the whole collection. To this end the QA uses k QBs and p LSs. The k QBs run on a front-end workstation, and fetch user queries from a shared message queue. Every fetched query is then broadcast to the associated p LSs (*workers*), possibly running on different workstations. The p LSs satisfy the query on the distinct subindexes, and return to the QB that submitted the query the first l references to most relevant documents contained within each subcollection. The QB waits for all the $l \cdot p$ results and chooses among them the l documents with the highest ranks. Finally, such results are returned to the requesting user. Figure 3 shows the logic structure of the MOSE architecture. A QB, along with the p associated LSs, implements a *data parallel* worker which concurrently serve the user queries. In order to manage concurrently more queries and to better exploit LSs' bandwidth, k QBs are introduced within a QA. System performances can be furthermore increased by replicating the QA in n copies.

All the parallelization strategies depicted in Section 1 can be thus realized by choosing appropriate values for n, k, and p. A pure task parallel approach

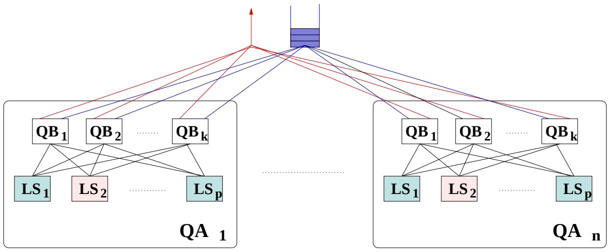


Figure 3. Structure of MOSE Query Analyzer.

corresponds to $p = 1$, while $n > 1$ and/or $k > 1$. By choosing $p > 1$, $n = 1$ and $k = 1$ we obtain a pure data-parallel implementation. A hybrid task + data parallel strategy is finally obtained for $p > 1$, while $n > 1$ and/or $k > 1$.

Indexer. The Indexer has the purpose of building the index from the gathered web documents. The indexing algorithm used is a parallel version of the *Sort Based* algorithm which is very efficient on large collections due to the good compromise between memory and I/O usage[2]. Moreover, the index built is *Full Text* and *Word Based*. The Lexicon is compressed exploiting the common prefixes of lexicographically ordered terms (*Shared Prefix Coding*), while the Postings lists are compressed by using the *Local Bernoulli* technique[2]. MOSE parallel Indexer exploits the *master/worker* paradigm and standard Unix SysV communication mechanisms (i.e. message queues). Since each subcollection of web documents is indexed independently (and concurrently on different workstations), the current Indexer implementation exploits parallelism only within the same SMP architecture. The master process scans the subcollection, and sends the reference to each document (i.e. the file offset) along with a unique document identifier to one of the worker processes on a self-scheduling basis. The workers independently read each assigned document from the disk and indexes it. When all documents have been processed, the workers write their local indexes to the disk, and signal their completion to the master. At this point the master merges the local subindexes in order to create a single index for the whole subcollection. A distributed implementation of the Indexer could be easily derived, but should require all the processing nodes to efficiently access the disk-resident subcollection, and that at least a single node can access all the subindexes during the merging phase.

Query Broker. Each QB loops performing the following actions:
Receipt and broadcasting of queries. Independently from the mechanism ex-

ploited to accept user queries (e.g., CGI, fast CGI, PHP, ASP), user queries are inserted in a SysV message queue shared among all the QBs. Load balancing is accomplished by means of a *self scheduling* policy: free QBs access the shared queue and get the first available query. Once a query is fetched, the QB broadcasts it to its p LSs by means of an MPI asynchronous communication.

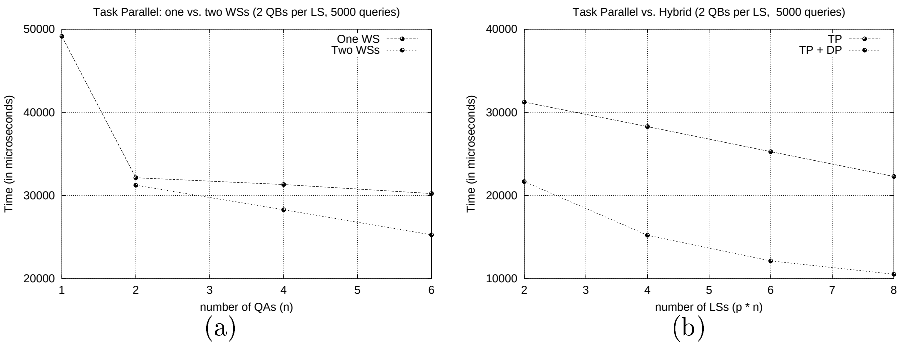
Receipt and merge of results. The QB then nondeterministically receives the results from all the LSs (i.e., p lists ordered by rank, of l pairs *document identifier*, and associated *rank value*) . The final list of the l results with the highest ranks is than obtained with a simple $O(l)$ merging algorithm.

Answers returning. The list of l results is finally returned to the CGI script originating the query that transforms document identifiers into `URLs` with a short abstract associated, and builds the dynamic `html` page returned to the requesting user.

Local Searcher. LSs implement the IR engine of MOSE. Once a query is received, the LS parses it, and searches the Lexicon for each terms of the query. Performance of term searching is very important for the whole system and are fully optimized. An efficient binary search algorithm is used at this purpose, and a *Shared Prefix Coding* technique is used to code the variable length terms of the lexicographically ordered Lexicon without wasting space[2]. Minimizing the size of the Lexicon is very important: a small Lexicon can be maintained in core with obvious repercussions on searching times. LS exploit the Unix *mmap* function to map the Lexicon into memory. The same function also allows an LS to share the Lexicon with all the other LS that run on the same workstation and process the same subcollection. Once a term of the query is found in the Lexicon, the associated posting list is retrieved from the disk, decompressed, and written onto a stack. The LS then processes *bottom-up* query boolean operators whenever their operands are available onto the top of the stack. When all boolean operators have been processed, the top of the stack stores the final list of results. The l results with the highest ranks are then selected in linear time by exploiting a *max-heap* data structure[2]. Finally, the l results are communicated to the QB that submitted the query.

4 Experimental Results

We conducted our experiments on a cluster of three SMP Linux PCs interconnected by a switched Fast Ethernet network. Each PC is equipped with two 233MHz PentiumII processors, 128 MBytes of RAM, and an ULTRA SCSI II disk. We indexed 750.000 multi-lingual html documents contained in the CDs of the web track of the TREC Conference and we built both a monolithic



(a) (b)

Figure 4. Results of the experiments conducted.

index ($p = 1$) and a partitioned one ($p = 2$). The monolithic index contains 6.700.000 distinct terms and has a size of 0.96 GBytes (1.7 GBytes without compression), while each one of the two partitions of the partitioned index occupy about 0.55 GBytes. The queries used for testing come from an actual query log file provided by the Italian WEB Search Company IDEARE S.p.A.

We experimented Task-Parallel (TP), and hybrid (TP + DP) configurations of MOSE. We mapped all the QBs on a single workstation, while the LSs were placed on one or both the other machines. Independently of the configuration used (one or two index partitions), two QBs were introduced ($k = 2$). Figure 4.(a) reports the average elapsed times, i.e. the inverse of the throughput, required to process each one of 5000 queries for the TP case ($p = 1$) as a function of n, i.e. the number of QAs exploited. The two curves plotted refer to the cases where the LSs were mapped on one or two SMP machines. We can see that when two QAs are used they can be almost indifferently placed on one or two SMP machines, thus showing the efficacy of the sharing mechanisms used. On the other hand, as we increase the number of QAs, the difference between exploiting one or two machines increases as well. We can also observe that it is useful to employ more QAs than the available processors.

Figure 4.(b) compares the TP solution with the hybrid one (TP + DP). Testing conditions were the same as the experiment above. In the case of the hybrid configuration, all the LSs associated with the same partition of the index were placed on the same workstation in order to allow the LSs to share the lexicon data structure. The better performance of the hybrid approach is evident. Superlinear speedups were obtained in all the TP + DP tests. They derive from a good exploitation of memory hierarchies, in particular of the buffer cache which virtualize the accesses to the disk-resident posting lists.

5 Conclusions

We have presented the parallel and distributed architecture of MOSE, and discussed how it was designed in order to efficiently exploit low-cost clusters of workstations. We reported the results of preliminary experiments conducted on three SMP workstations. The results highlighted the greater performances resulting from exploiting a hybrid *Task + Data* parallelization strategy over a pure *Task-parallel* one. There are a lot of important issues we plan to investigate in the near future. The most important is performing an accurate testing of MOSE on larger clusters and document collections in order to analyze in greater detail the scalability of the different parallelization strategies. Fastest interconnection network such as Myrinet have also to be tested. Moreover, we are interested to study query locality and the effectiveness of caching their results within QBs, and "supervised" document partitioning strategies aimed at reducing the number of index partitions needed to satisfy each query.

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