Evaluating Communication Strategies in a Multi Agent Information Retrieval System

David Lillis[1], Rem Collier[1], Fergus Toolan[2], and John Dunnion[1]

[1] School of Computer Science and Informatics
University College Dublin
{david.lillis, rem.collier, john.dunnion}@ucd.ie
[2] Faculty of Computing Science
Griffith College Dublin
fergus.toolan@gcd.ie

Abstract. With the complexity of computer systems increasing with time, the need for systems that are capable of managing themselves has become an important consideration in the Information Technology industry. In this paper, we discuss HOTAIR: a scalable, autonomic Multi-Agent Information Retrieval System. In particular, we focus on the incorporation of self-configuring and self-optimising features into the system. We investigate two alternative methods by which the system can configure itself in order to perform its task. We also discuss the Performance Management element, whose aim is to optimise system performance.

1 Introduction

Complexity is a serious issue with modern computer systems. As hardware has improved dramatically to facilitate the development of more and more powerful systems, the complexity of the software that runs on it has increased accordingly. As a result of this, the costs associated with administrating such systems has become a serious issue in the Information Technology industry.

This has resulted in a push towards the development of software systems that are capable of managing themselves, in order to reduce the input required from human administrators. Research in this area has come to be referred to as Autonomic Computing, a term coined by IBM in 2001 [1]. Essential features of an autonomic computing system include self-configuration, self-optimisation, self-protection, self-healing and a number of others [2–4].

In addition to these hardware and software changes, another feature of the computer industry in recent years has been the widespread adoption of the World Wide Web. This has resulted in a dramatic increase in the quantity of information being made available, through such things as news articles, blog entries and forum postings. As a result, Information Retrieval (IR) systems must be capable of dealing with more and more information, which has resulted the need for more sophisticated systems. Efficiency and scalability have been of increasing concern in the IR community, along with the presentation of high-quality results.

The development of IR systems using multi-agent techniques is not a new phenomenon [5–7]. Indeed, the aim of our work on HOTAIR (Highly Organised Team of Agents for Information Retrieval), a multi agent IR system with autonomic features [8], is not to demonstrate innovation in the development of multi-agent IR systems, but rather to investigate a range of techniques that will enhance the robustness and scalability of large-scale agent systems. Here, we focus on two approaches to agent interaction that facilitate self-configuration.

Accordingly, Section 2 outlines reasons why IR is an ideal testbed for an Autonomic Computing System. Section 3 presents a general overview of the HOTAIR architecture, of which two versions have been developed. The first incorporates a Broker agent which maintains a centralised view of the entire system and manages the behaviour of other agents. An alternative architecture allows individual agents more autonomy by allowing them to gather more knowledge about their environment. Each version features a Performance Manager to provide elements of self-optimisation. Section 4 outlines experiments carried out to compare the performance of these two architectures. Finally, we include our conclusions and ideas for future work in Section 5.

2 Information Retrieval as an Autonomic Computing Testbed

An IR system is an ideal testbed for autonomic computing for a number of reasons. Firstly, a number of essential features of autonomic computing systems that have great relevance to IR systems:

- **Self-Configuration:** As more and more information becomes available to be processed by IR systems, it becomes necessary for the systems themselves to grow accordingly. This necessitates the introduction of additional hardware into the system, to cope with the increased workload. As it would be unfeasible to merely transfer the data from one system to another, it is necessary to add this hardware while the system is running. A self-configuring system would be capable of incorporating these additional resources into the system and make use of them, without intervention by a human administrator.
- **Self-Optimisation:** As with any large-scale system, optimal use of the available resources is an important aim. A self-optimising system will monitor its own use of resources and can react immediately to exploit any opportunities for greater performance that may arise.
- **Self-Healing and Self-Protection:** Recovery from failures and protection from external attack are essential to ensure reliability in any large-scale system, including an IR system. Given the huge revenues that are earned in advertising alongside, for example, online searches, prolonged downtime could have disastrous consequences for popular IR systems.

In addition to the above, the IR domain is an attractive one in which to carry out research on autonomic computing. The barriers to entry are low, as an IR system can be run on a cluster of low-end desktop computers. Also, the existence of open source IR libraries such as Lucene[3] and Xapian[4] mean that the learning curve in setting up an IR system is relatively shallow in comparison to some other domains.

3 The HOTAIR Architecture

HOTAIR is an Information Retrieval system developed as a Multi-Agent System. It is written in the AFAPL2 agent programming language [9] and runs within the Agent Factory framework, a FIPA-compliant runtime environment for agents [10, 11]. The aim of the HOTAIR project is the development of a reliable and scalable agent-based search engine architecture. As discussed in Section 2, this application domain was chosen because we believe that IR is a problem that offers significant challenges in terms of the scale of the applications, which invites the use of autonomic features. Consistent with a typical IR system, HOTAIR consists of two distinct subsystems:

The Indexing Subsystem is reponsible for identifying new documents to make available to users, whether from the World Wide Web, an FTP site, a ZIP archive, a file share or some other source. These documents must be added to a searchable index from which results will be extracted to be presented to users.

The Querying Subsystem is responsible for accepting queries from users, running those queries against the index built up by the Indexing Subsystem and returning those results to the user.

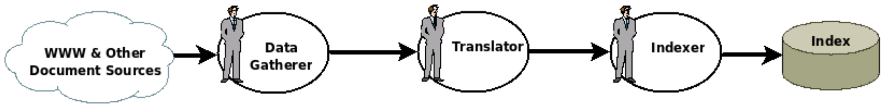

Fig. 1. Flow of documents through the HOTAIR Indexing System

The focus of this paper is on the Indexing Subsystem. In order for a document to be added to the index, it must go through three stages, illustrated in Figure 1. Each of these three steps is carried out by what is referred to as a “core agent”. *DataGatherer* agents are responsible for identifying and collecting new documents for inclusion in the index. These documents may be taken from any number of sources and may be in a variety of file formats. *Translators* are necessary to interpret the documents of various file types that have been collected by the DataGatherers. These are converted into a common file type, known as the HOTAIR Document Format (HDF), which maintains an XML representation of the document contents. *Indexers* represent the final step that a document must go through in order to be included in the system’s index. Indexer agents accept

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[3] http://lucene.apache.org

[4] http://www.xapian.org

HDF documents as their inputs, extract the contents from these documents and save this data in the index. In order to reduce the amount of communication necessary between agents, documents are not processed individually, but rather in bundles of 20. We refer to these bundles as “jobs”.

Initially, core agents are not aware of the location of other core agents. The discovery of, and interaction with, other relevant core agents is an element of self-configuration which we aim to introduce in the following sections. During the development process, two versions of the HOTAIR architecture were created. The principal difference between these is the way in which agents gain knowledge about their environment and discover other agents with which they must interact in order to carry out their tasks. Section 3.1 describes the basic workflow of the system, which both architectures share. Of the two architectures, the “broker architecture” uses a Broker agent to micro-manage the behaviour of the core agents. This is presented in Section 3.2. Section 3.3 presents the alternative “broadcast architecture”, in which the core agents have more control over their own behaviour, as they have access to more information about the state of other agents and of the system as a whole. Finally, section 3.4 describes the performance management features that are applicable to both architectures.

3.1 Indexing System Workflow

This section describes the workflow of the HOTAIR Indexing Subsystem: how the core agents interact with one another in order to include documents in the index. Activities discussed in this section are carried out by core agents in both the brokered and broadcast architectures. We use the term “Processor” to describe any agent that receives jobs from another agent and processes them in some way (i.e. Translators process jobs taken from DataGatherers and Indexers process jobs taken from Translators). “Provider” is a generic term to refer to any agent that provides jobs for a Processor (i.e. DataGatherers provide jobs for Translators, which in turn provide jobs for Indexers).

At any given time, each Processor is assigned to a single Provider, from which it receives documents for processing. The way in which this assignment takes place is the fundamental difference between the brokered and broadcast architectures and is discussed in detail in the following sections.

The actual flow of jobs through the system then follows a pull-style pattern. When a Processor has the capacity to process a job, it requests a job from the Provider to which it is assigned. Each Provider maintains an output queue, which contains jobs on which it has completed its own processing. It is from this queue that a job is taken and forwarded to the Processor that requested it. If the Provider’s output queue is empty, it will reply with that information, at which time the Processor must be reassigned to an alternative Provider. The Performance Manager (discussed in Section 3.4) is charged with ensuring that the system is balanced so there are always documents available for processing.

Once the Processor has finished processing the job, it adds the job to its output queue if it is also a Provider. Indexers do not have output queues, as they represent the final stage of processing a document must undergo.

3.2 Brokered Architecture

The Brokered version of HOTAIR employs a Broker agent to aid the core agents in the discovery of the other core agents with which they need to communicate and interact. Brokers have long been seen as a useful design pattern for creating more open agent systems [12, 13]. Here, the core agents have no first-hand knowledge of their environment other than the location of the Broker agent.

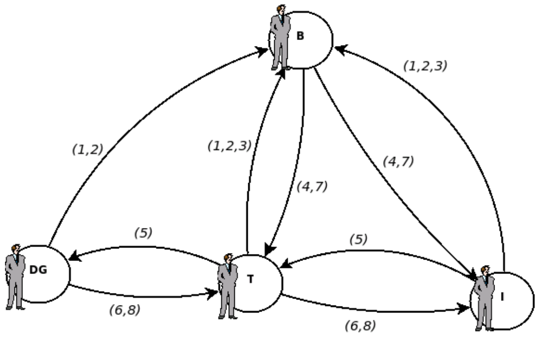

Fig. 2. Communication in the Brokered Architecture

Figure 2 illustrates the communications between agents in the Brokered Architecture. For simplicity, only one agent of each type is shown, though many DataGatherers, Translators and Indexers may exist in practice. Upon creation, each new core agent must register with the Broker (shown as communication *(1)* in Figure 2) and is included in the model the Broker uses to assign Processors to Providers. Each Provider periodically contacts the Broker to inform it of the number of jobs currently contained in its output queue *(2)*. This allows the Broker to build a model of the amount of work being created for each category of Processor.

In order to find jobs to process, a Processor must contact the Broker and request that it be assigned to a Provider *(3)*. The Broker then makes use of its knowledge of the output queue status of the relevant Providers and of the assignments it has already made to make the most appropriate assignment *(4)*. A Processor will continue requesting jobs from the same Provider *(5,6)* until either the Broker reassigns it to a different Provider *(7)* or the Provider informs it that its output queue is empty *(8)*. In the latter case, the Processor must re-contact the Broker to be reassigned to an alternative Provider.

A key advantage of such an architecture is that all agent assignments are made with full knowledge of the state of the system as a whole. Thus, the allocation of agents can at all times be balanced so as to ensure that all Providers will eventually have Processors assigned to them. Assuming the Broker is using an appropriate assignment algorithm, this has the effect that jobs cannot become held up in a situation where they are located in the output queue of a Provider that never has a Processor assigned to it.

This form of Broker agent does, however, introduce a single point of failure into the system. If Broker fails or becomes uncontactable, the system as a whole will also fail. Core agents will no longer be able to identify Providers, as they will not have a method of finding their location. As the Broker is also the sole agent that is aware of the type, location and status of the core agents, this information is also lost if the Broker fails. In order to overcome this limitation, work has been carried out on the development of robust brokered architectures in order to maintain system performance in the event of the failure of the Broker [14].

3.3 Broadcast Architecture

The second version of the HOTAIR architecture involved Providers broadcasting the state of their output queues to all other core agents, rather than just to a centralised Broker agent. Specifically, a wild card ("*") was introduced into the agent name component of the FIPA agent identifiers allowing the partial specification of receiver agents. An example of this would be the agent identifier $agentID(ind*, addresses(http://localhost:444/acc))$[5], which could be used to send a message to all agents on the specified agent platform whose name beings with "ind" (which, in conjunction with an appropriate naming scheme, could be used to contact all Indexer agents). Furthermore, replacing "ind*" with "*" is akin to a broadcast to all agents on the specified agent platform. Following this, a UDP multicast Message Transport Service was introduced, which, together with the wild card, allowed broadcasting of message to all agents on all platforms that are listening via the relevant UDP agent communication channel.

By introducing the above message broadcasting mechanism, and allowing Providers to broadcast their state, the need for the Broker agent is removed. Each core agent can build its own model of its environment and decide for itself which Provider from which it will request jobs. Perhaps the key issue in employing a UDP-based agent communication channel is that agent communication is no longer guaranteed. However, so long as the approach is used judiciously (e.g. repeated broadcasting of status updates) and in conjunction with guaranteed communication mechanisms (e.g. for job requests) the overall behaviour of the system can be guaranteed without affecting the robustness of the system. For some tasks, however, it would be useful to have the ability to broadcast reliably, and so we intend to investigate alternative methods of broadcasting using XMPP-based technologies such as Jabber[6].

The broadcasts made by core agents include information about the length of their output queue, the number of documents in jobs processed and the time taken to perform this processing. In addition to being used by other core agents to support the system workflow, it is also possible for a Performance Manager to make use of this information to influence its management decisions.

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[5] This identifier is specified in the format that is employed by the AFAPL programming language

[6] http://www.jabber.org

Using this broadcast architecture, assignment of Processors to Providers is carried out by the Processors themselves. By default, agents assign themselves to the Provider that has most recently broadcasted the largest output queue. This self-assignment allows the agents to maintain the functioning of the system even in the absence of any management agents, thus removing the single point of failure without the need to introduce additional strategies to improve the robustness of the Broker. This self-assignment can, however, be overridden by instructions from a Performance Manager agent to assign it to another Provider. Once a Processor has assigned itself to a provider, it requests jobs in the same way as in the Brokered Architecture. On receipt of a message to inform it that its Provider no longer has any jobs available for processing, a Processor will reassign itself to another Provider.

3.4 Performance Management

Self-optimisation of the system is carried out by a centralised Performance Manager. The aim of this manager is to maximise throughput. In order to carry out this task, it has a number of actions available to it so as to alter system behaviour.

Agent Reassignment: In the broadcast architecture, agents will by default assign themselves the Provider with the greatest number of outstanding jobs. However, this does not necessarily lead to optimal system performance as it is not optimised for the system as a whole. The Performance Manager may override this default behaviour so as to improve system efficiency. In the brokered architecture, all agent assignments are performed by the Broker, which doubles as the Performance Manager.

Group Halting/Resumption: Whenever a Provider group processes jobs quicker than the agents assigned to it, the Performance Manager may instruct members of that group to temporarily cease processing jobs, so as to allow the backlog to be cleared.

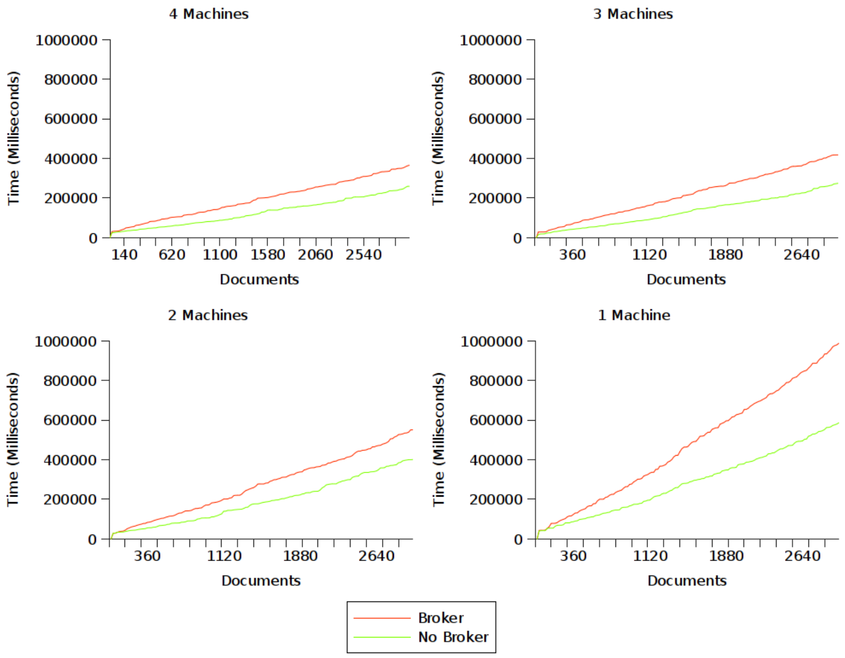
Agent Creation: Initially, the system begins with a small agent community. Once the system is running, the Performance Manager incrementally increases the size of the agent community by creating agents for the group it believes will benefit most by the creation of an additional agent.

Agent Destruction: When the system reaches its maximum capacity (i.e. no more agents can be created), the Performance Manager investigates whether it is possible to create free space for new agents by destroying unnecessary agents, or agents from overpopulated groups.

4 Experiments and Evaluation

In order to compare the performance of the brokered and broadcast architecture, a number of experiments were run. Each time the system was run, three Data-Gatherers were created, each gathering documents from a different document

Fig. 3. Document Indexing Speed



collection. The collections used were Cranfield, NPL and the 2Gb Web Track collection from the TREC conference.

The number of machines available to the system was increased so as to evaluate the scalability of each of the two architectures. Each machine is a standard desktop computer running an Agent Factory agent platform, on which the agents run. The creation of agents on any of these platforms was the decision of the Performance Manager, which was present for both architectures. In the brokered architecture, the Performance Manager also took on the the role of a Broker. The maximum number of agents that could be created on each platform was manually set at 15. Systems were evaluated by their performance in successfully indexing 3,000 documents. As the document collections contain more than 3,000 documents, in each case all elements of the system were still running on the termination of the experiment. The results of running these experiments on between 1 and 4 machines are displayed in Table 1 and Figure 3. In each case, the system was run three times and all values used are the average of these three runs. Figure 3 shows the number of documents indexed by each system configuration over time. Table 1 shows the overall time taken to complete the indexing of the 3,000 documents.

For each configuration of the system, the broadcast architecture outperformed the brokered architecture to a large degree. The extent of this difference

Table 1. Time to index 3,000 documents (in milliseconds)

	Broker	Broadcast	% difference
1 machine	987849	585957	-40.68%
2 machines	551573	400895	-27.32%
3 machines	418200	274210	-34.43%
4 machines	365612	259286	-29.08%

was always in excess of 27%. The addition of an extra machine reduced the total processing time in each case, as expected. An interesting feature to note is that the impact of the addition of the fourth machine was not as dramatic as that of the second or third machines. This would suggest that the Performance Manager is not currently making full use of the resources being made available to it. Although this is an interesting observation, it does not affect the comparison between the brokered and broadcast architectures, as the same performance management strategy was used in both.

5 Conclusions and Future Work

This paper evaluates two approaches to agent interaction that have been employed in the HOTAIR architecture. The first approach, which is presented in Section 3.2, is based on best practices and employs a Broker as a middle agent, which manages interactions between the underlying core agents (DataGatherers, Translators and Indexers) through the maintenance of a model of the current state of the system. In contrast, the second approach, which is presented in Section 3.3, removes the need for a broker through the introduction of a UDP-based broadcast mechanism and the incorporation of a partial system model internally within each core agent.

Central to both architectures is the Performance Manager, builds an extended model of the system state that includes location and assignment information. The Performance Manager performs periodic analysis of the current system state, modifying the assignments between core agents in order to improve the performance of the system. It is also empowered with a number of other actions it can take to optimise system performance.

As is shown through the results presented in Section 4, the broadcast architecture consistently outperforms the broker architecture by more than 27%. This is in addition to the advantages it provides in terms of robustness.

Future work will involve further investigation on the scalability of the system on larger clusters of machines. Additionally, we aim to focus on the development of appropriate self-optimisation algorithms, which will make best use of the available performance management actions (outlined in Section 3.4) so as to increase system throughput. Another key element of autonomic computing which we aim to address is self-healing, which should ensure that the system should be capable of tolerating and recovering from agent failures, while ensuring that all documents are successfully indexed.

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