CHAPTER 1

INTRODUCTION

Applications requiring intensive problem-solving capabilities have highlighted the need for dynamic behavior oriented systems. Though being complex in nature, systems in all enterprises are needed to solve the problems ranging from scientific studies, commercial solutions to academic endeavors.

‘Information’ is vital for the success of any enterprise and in general any human endeavor. Acquisition, storage and retrieval of information are key challenges faced by the information providers and consumers today. Access to current scientific, engineering, and other technical information is the foundation for acquiring global competitiveness in any chosen field. However, access to publications is often too hard and / or too expensive for individuals or libraries. This is proving to be the ‘Achilles heel’ of the entire scientific publication process.

Usage of Information and Communication Technologies has paved way for the creation of ‘Digital Libraries’. These libraries promise to enable the right information to reach the right person or persons at the right time. They provide the platform for life-long learning.

In 1993, when the National Science Foundation prepared the “Source Book on Digital Libraries”, (Edward A. Fox, 1993) it was estimated that
nearly 100,000 volumes or 50,000,000 pages must be converted into the
digital form. If an OCR is used to digitize these pages it would result in about
10 Terabytes of public information. The Internet provided access to 20-50 Terabytes of Public Information in 2000. The amount of information
accessible using the Internet in 2003 is estimated to be 167 Terabytes. This
rapid growth in the quantum of accessible digital information was possible
largely due to the falling prices of scanning devices, highly accurate OCRs
and storage devices. The ICT made rapid progress during this time period
making browsing feasible worldwide.

However, digital libraries brought into sharp focus several key
problems pertaining to the users. Improving the efficiency of retrieving the
desired information by any given user of the digital library has proven to be a
major challenge. It is often observed that information needs of a given user,
more often than not, tend to be unique to that user. Hence storing the
information to maximize retrieval efficiency for a given user population needs
clever classification schemes. This work reports a mathematical model that
results in improved efficiency of retrieval and improved relevance of the
retrieved information. The model is for geographically distributed digital
libraries. It can also be used for generic information repositories.

The mathematical model is implemented using a multi-agent system.
Information environments like the Internet require dynamic, autonomous,
optimized, intelligent, proactive and complex solution mechanisms for various
purposes. The web digital library is one such information environment and is
distributed, large, open and heterogeneous in nature. This increasing
complexity of web digital library is complemented by an increasing
complexity of their applications. The Multi-Agent System promises to play an
important role in developing and analyzing models to solve such complex
problems. An agent in a multi-agent system
Decomposes its goals and tasks, allocates sub-goals and sub-tasks to various other agents and synthesizes partial results and solutions.

- Represents and reasons about the actions, plans and knowledge in order to solve the complex tasks.
- Realizes intelligent processes such as problem solving, planning, decision-making and learning in order to collectively carry out such tasks in a coherent way.
- Solves issues and contributed to research in the domain-specific areas with certain restrictions.

The appropriate mathematical model implemented in this work provides a coherent classification scheme and content allocation. This results in a storage methodology that provides efficient retrieval for a set of user patterns of access. The multi-agent based implementation factors these user patterns of access in a distributed system of digital libraries. The implementation can be used over any distributed digital repository of information.

1.1 OVERVIEW OF INTELLIGENT MULTI-AGENT SYSTEM

An agent is a computer program (Michael Wooldridge 2002) that is situated in some environment, and that is capable of autonomous action in order to meet its design objectives. As an intelligent entity (Gerhard Weiss 1999), an agent operates flexibly and rationally in a variety of environmental circumstances given its perceptual and effectual equipment. An agent, on the basis of key processes such as problem solving, planning, decision-making and learning achieves behavioral flexibility and rationality.
In general there is no universally accepted definition of the term ‘Agent’ and that autonomy is central to the notion of agency. One of the definitions of the notion of autonomy explains that without human interaction the system is able to perform the task. That is, it has control over the internal state as well as behavior. The second definition explains that in most domains of reasonable complexity, an agent will not have complete control over its environments. It will have at best partial control, in which it can influence.

One of the primary paradigms of Distributed Artificial Intelligence (Gerhard Weiss 1999) system is multi-agent system in which several such agents coordinate their knowledge and activities in order to solve a problem in a complex network environment. In the distributed problem solving systems the work of solving a particular problem is divided among a number of agents that divide and share knowledge about the problem and the developing solution. The traditional Artificial Intelligence (AI) concentrates on agents as “intelligence stand alone systems” and on intelligence as a property of systems that act in isolation. Distributed Artificial Intelligence (DAI) concentrates on agents as “intelligent connected systems” and on intelligence as a property of systems that interact. Where traditional AI focuses on “cognitive processes” within individuals, DAI focuses on “social processes” in a group of individuals. Where traditional AI considers systems having a single focus of internal reasoning and control and requiring just minimal help from other to act successfully, DAI considers systems in which reasoning and control is distributed and successful activity is a joint effort. Where as traditional AI uses psychology and behaviorism for ideas, inspiration, and metaphor, DAI uses sociology and economics. In this way, DAI is not as much as specialization of traditional AI, but a generalization of it.
The key problem facing an agent is that of deciding which of its actions it should perform in order to best satisfy its design objectives. Agent architecture for decision-making process can be affected by a number of different environmental properties. Russell and Norvig (Stuart Russell 2003) suggest the following classification of environment properties.

- **Accessible Vs. Inaccessible**
  An accessible environment is one in which the agent can obtain complete, accurate and up-to-date information about the environment’s state. Most moderately complex environments are accessible. The more accessible an environment is, the simpler it is to build an agent to operate in it.

- **Deterministic Vs. Non-deterministic**
  A deterministic environment is one in which any action has a single guaranteed effect—there is no uncertainty about the state that will result from performing an action. The physical world can do all intents and purposes. This is regarded as non-deterministic. Non-deterministic environments present greater problems for the agent designer.

- **Episodic Vs. Non-episodic**
  In an episodic environment, the performance of an agent is dependent on a number of discrete episodes, with no preferences between the performances of an agent in different scenarios. Non-episodic environments are simpler from the agent developer’s perspective because the agent can decide what action is necessary to perform based on the current episode. It need not reason about the interactions between this and the future objects.
• **Static Vs. Dynamic**

A static environment is one that can be assumed to remain unchanged except by the performance of actions by the agent. A dynamic environment is one that has other processes operating on it and hence changes its ways beyond the agent’s control. The physical world is a highly dynamic environment.

• **Discrete Vs. Continuous**

An environment is discrete if there are a fixed, finite number of actions and percepts in it. Russell and Norvig give a chess game as an example of a discrete environment and taxi driving as an example of a continuous one.

1.1.1 **Characteristics of Intelligent Multi-Agent Systems**

The characteristics of intelligent agents exploit the dynamic nature. The characteristics of the intelligent agents can be classified into two categories, such as internal (intra) and external (inter) characteristics (Walter Brenner 1998). The internal characteristics are autonomy, reactivity, proactiveness, goal-orientation, mobility, learning ability and adaptability. The external characteristics are communication, cooperation, coordination and self-proclamation.

1.1.1.1 **Autonomy**

The autonomous agents (Walter Brenner 1998, Dimitris N. Chorafas 1998, Hyacinth S. Nwana 1996b, Stan Franklin 1996) are capable of following their goals independently. An agent must have control over its actions and internal states. This important behavior differentiates agents from non-intelligent agents. An agent does not need to have each of its steps approved
by its user or other agents. It is capable of acting alone. Also the degree of autonomy varies for each software agents. It must have a certain minimum degree of intelligence in order to be designated as being an agent because it acts as a virtual person to the user. The intelligence of an agent is formed from three main components. (a) Its internal knowledge base, (b) Its reasoning capability and (c) Adaptive behavior.

1.1.1.2 Reactiveness

Agent is able to react (Stuart Russell 2003, Walter Brenner 1998, Hyacinth S. Nwana 1996b, Stan Franklin 1996) to the specific action in the environment. It is the fundamental characteristic of any agent. It does any one of the specific actions defined in the agent. It is able to change its action according to the environment.

1.1.1.3 Proactiveness/Goal-orientation

Proactiveness (Walter Brenner 1998, Hyacinth S. Nwana 1996b) is above the level of reactiveness. It has a good understanding about the environment, because it takes specific initiative under specific circumstances of its own in order to accomplish its goal. This is also described as goal orientation because the capability of an agent itself is to take initiative. It requires that the agent has well defined goals or even a complex goal system.

1.1.1.4 Stationary/Mobility

possess the ability to communicate with other agents in the communication network. Remote Procedure Call (RPC) is the basis for possible implementation of stationary agents. Mobility is an important characteristic that permits the agent to migrate to different nodes in the electronic network. This mobile agent can be either a mobile script or mobile object. Mobile scripts are explicitly transferred to the target node but the mobile objects are capable of transferring itself to the target node. Remote programming (RP) is the basis for implementation of mobile agents.

1.1.1.5 Learning ability / Adaptiveness

The agent has the ability to adapt (Walter Brenner 1998, Borking.J.J 1999, Hyacinth S. Nwana 1996) to the changes in the environment. The agent’s reasoning power should have a certain amount of rationality. The agent perceives the changes in the environment; it identifies the pattern of functioning of the environment and tries to adapt that pattern.

1.1.1.6 Communication

In a Multi-Agent System independent agents (Gerhard Weiss 1999, Walter Brenner 1998, Michael R. Genesereth 1994) are communicating with each other. These communications are referred to as high-end communications. There are a number of communication protocols and sometimes these are referred to as Agent Communication Languages (ACL).

1.1.1.7 Cooperation/Coordination

Communication is the basis for this cooperation (Walter Brenner 1998, Hyacinth S., Nwana 1996b, Katia Sycara 1996). In order to cooperate, it
needs to possess a social ability, that is, the ability to interact with other agents. A cooperation topology defined by Franklin in 1997 is shown in Figure 1.1. It differentiates the top layer from independent and cooperative agents. If the individual agents of a multi-agent system are completely independent of each other and follow their own goals, it is described as an independent system. If the independently acting agents also have non-correlated goals, then the system is termed as discrete. Systems with emergent cooperation develop when agents independent of each other follow the same goals and hence from the outside, give the appearance of cooperation. For example, if several agents independently of each other follow an identical goal, a non-participating observer can have the impression of a cooperative methodology.

Cooperative systems have explicit cooperative mechanisms. The agents are constructed in a way that they can cooperate with other agents to achieve their goals. Such agents make intentional use of this capability. It is considered that the cooperation can precede either communicatively or non-communicatively.

Communicative agents use communication protocols and procedures to cooperate with other agents. This communicative cooperation takes place indirectly using the environment. An agent observes its environment, and in this manner, notices changes caused by other agents. Its response to these changes, in turn, causes a response to other agents observing the environment. This is the way an indirect cooperation occurs.

Communicative cooperation agents can be divided into deliberative and negotiating agents. A common planning and agreement of the methodology occurs between all agents in a deliberative agent system. In negotiation-oriented methodologies, a number of agents are competing with each other to solve a particular problem openly available in the environment. The negotiations can resolve conflicts and assign tasks.
Coordination is a centralized strategy in which a particular agent takes the responsibility. It decomposes the task into subtasks based on the domain specific knowledge and then delegates the subtasks to other task specific agents. The task-specific or coordinating agent will then take the responsibility for collecting data, resolving conflicts, coordinating the related agents and finally report the result to the user.

1.1.1.8 Self-proclamation

It is a specific type of cooperation in which it is able to share its knowledge voluntarily, if any specific tasks or information requirement arises.

1.1.1.9 Personal Characteristics

These personal characteristics (Walter Brenner 1998) are trustworthiness, reliability and security. Security is the most important characteristic for reliability and trustworthiness.

![Figure 1.1 An Agent Cooperation Topology](image-url)
1.1.2 Intelligent Multi-Agent System Architectures

Architecture is described as a particular methodology for building agents. It specifies how the agent can be decomposed into construction of a set of component modules and how these modules should be made to interact. There are a number of Agent Architectures developed by various people at different occasions. These may be classified into four major categories such as Logic based Agents, Reactive, Deliberative and Hybrid Agents (Stuart Russell 2003, Walter Brenner 1998). These classifications are purely based on various components that an agent includes.

1.1.2.1 Logic Based Agents

The “traditional” approach to building artificially intelligent systems, (known as symbolic AI) suggests that the intelligent behavior can be generated in a system by giving that system a symbolic representation of its environment, its desired behavior and syntactically manipulating this representation. The decision-making is realized through logical deduction.

1.1.2.2 Deliberative Architecture

This follows the classical AI intelligent system design approach and has assumed an explicit symbolic model of the environment and the capability of logical reasoning as the bases for intelligent actions. The modeling of the environment is normally performed in advance and forms the main component of the agent's knowledge base. The actual conversion and selection of a suitable representation language are particularly difficult. Because of the high complexity of such representations, deliberative agents have only limited suitability for use in dynamic environments. In addition to its internal
symbolic environment model, it also has the ability to make logical decisions. The architecture of the deliberative agents is shown in Figure 1.2. Although a deliberative agent has access to information receivers, these are infrequently used to extend the knowledge base. Thus the main criticism lies in its rigid structure. It is not possible for deliberative agents to work in a dynamic environment because of its complex nature. The scheduler, planner and executor take a lot of time to perform their operations.

1.1.2.2 Reactive Agents

In the case of reactive agents, intelligent behavior is possible even without explicit knowledge representation and abstract reasoning capabilities. Reactive agents do not possess an internal symbolic model of their environment and they can operate quickly and efficiently because they sense and respond to any change in the environment using sensors and reactors. A reactive agent must not necessarily have a complex structure to be able to act within a complex environment.
It suffices to precisely observe the environment and to recognize a range of simple principles or dependencies. This knowledge is used to develop task specific modules that are capable of continuously checking their environment for the occurrence of specific situations and to initiate direct reaction when such a situation occurs. The following Figure 1.3 shows the architecture of reactive agents defined by Brooks in 1986.

Agent sensors record information, forward it to the task specific competence modules and hence produce a reaction of the competence module, which actuators transfer to the environment. The competence modules work in a parallel mode. These competence modules are arranged in a hierarchical manner. The modules located at the lower end of the hierarchy are responsible for the basic, primitive tasks, whereas the higher modules reflect more complex behavior patterns. A reactive agent cannot solve any task for which no competence modules exist. Every competence module can operate autonomously and higher modules incorporate a subset of the tasks of the subordinate modules and hence the name Sub-sumption architecture.

1.1.2.3 Hybrid Architecture

Hybrid architecture is a combination of the reactive and deliberative components of agents modeling to produce a more powerful model. Whereas the reactive component is primarily used for the interaction with the environment, the deliberative systems concentrate on the area of planning and decision-making. The system architect is responsible for the weighting of the individual components and assumes priority for the decisions. Hybrid systems are normally designed as an hierarchical architecture with an increasing degree of abstraction. The lower levels are formed by reactive systems and are used for the acquisition of raw information. Deliberative components for long-term goal determination and planning are used in the upper levels.
Figure 1.3 Architecture of Reactive Agents (based on [Books 1986])

The Interrap architecture from Muller is a typical example of a hybrid agent system, which is described as a multi-layer architecture as shown in Figure 1.4. Where the agent's basic behavior pattern is implemented in the lower layers, which corresponds to the reactive component, the deliberative processes of goal formation, reasoning and planning are performed in the higher layers. This principle is presented in three layers of the Interrap architecture, the behavior based layer, the local planning layer and the cooperative planning layer. The appropriate belief models describe every situation. The architecture is based on number of design principles

- The three-layer structure describes an agent using various degrees of abstraction and complexity.
- Not only the control processes, but also the agent's knowledge base are multi-layered.
- The control process is bottom-up, in that, a layer receives control over a process only when this exceeds the capabilities of the layer below.
- Every layer uses the operation primitives of the lower layer to achieve its objective.
The interrap architecture consists of three major components: Knowledge base, control unit and World interface. The agent uses the world interface to maintain contact with its environment. The knowledge base consists of three levels of belief models. The control unit also consists of three layers that closely correspond to those of the knowledge base. The behavior-based layer describes the reactive capability of the agent. It is used when time critical situations demand fast responses. The local and cooperative planning layers form the agent’s deliberative components. They are used when a situation exceeds the capabilities of the behavior-based layer and demands longer-term objectives of determination and planning.

Every control unit consists essentially of two modules: the situation recognition/goal activation (SG) module and the planning/scheduling (PS) module. The SG module performs all steps described as part of the conceptional model. The PS module then performs the planning process, the provision of intentions and the scheduling.

Figure 1.4 Interrap Agent Architecture [Miller 1996]
1.2 PROBLEMS AND ISSUES OF DIGITAL LIBRARIES

Digital Libraries (William Arms 2000) hold any information that can be encoded as sequences of bits. Sometimes these are digitized versions of conventional media, such as text, images, music, sound recordings, specifications and designs and many more. As digital libraries expand, the contents are rarely the digital equivalents of physical items and more often items that have no equivalent such as data from scientific instruments, computer programs, video games, and databases. The digital libraries can be distributed in various physical locations. The Ontology based approach used in this work factors the problems of digital library.

The design and development of these digital libraries meet a lot of issues, such as digital library infrastructure and architecture, human-computer interaction, information retrieval, information mining, ontology based services, semantic web, multi-lingual access semi structured data management, text classification, web information gathering, information filtering, information extraction, hypertext and multimedia, security and privacy, document generation and electronic publishing, collection development and management, intellectual property, storage management, provision of service, user communities, web cataloging, metadata and content, digital preservation, digital archives and museums, knowledge management, content management etc. Most of the problems are interdependent. Even though the collection is confined to set a boundary for the digital library, most of the problems exist in the Internet also. The characteristics (Katia Sycara 2001) of Multi-Agent Systems are that

- Each agent has incomplete information or capabilities to solving the problem
- There is no system global control
• Data are decentralized
• Computation is asynchronous.

These characteristics are dominant in case of digital library problems and so the Multi-Agent System is taken as the best paradigm to find the solution to this problem.

In this research there are four such problems taken for investigation and they are

• Dynamic optimal content allocation method for web digital libraries.
• Design and development of intelligent agent proxy for digital libraries.
• Text classification for digital libraries
• User-adaptive retrieval for the collection of research literature.

1.3 NEED FOR INTELLIGENT MULTI-AGENT TO DIGITAL LIBRARIES

Digital Libraries are modern social and virtual institutions for information collection, preservation and dissemination, to be distributed across the world. The web digital library is one such information environment and is distributed, large, open and heterogeneous in nature. The design and development of digital library requires addressing of many issues (Daniel Andresen 1996, Dieter W. Fellner 2003, Frew J. 2000, Cezary Mazurek 1999, Raj Reddy 1999, Leon Zhao J. 1999) and must be able to perform intelligent human-cognitive tasks in order to make it highly sophisticated and effective. This increasing complexity of web digital library enables us to identify the best-fit technology to solve the problems.
An agent is an intelligent entity that operates flexibly and rationally in a variety of environmental circumstances given its perceptual and effectual capacities. An agent on the basis of key processes such as problem solving, planning, decision-making and learning achieves behavior flexibility and rationality. In multi-agent systems several agents coordinate their knowledge and activities and reason about the processes of coordination. In distributed problem solving systems the work of solving particular problem is divided among a number of nodes that divide and share knowledge about the problem and developing solution. An agent in the multi-agent system is able to communicate, cooperate and coordinate the task in the environment. The long-term goal of multi-agent system is to develop mechanisms and methods that enable agents to interact with humans and to understand interaction among intelligent entities whether they are computational, human or both. The multi-agent system will be an ultimate solution to the problems and issues of the web digital library. It will also be more optimal to use such a technology.

1.4 CONTRIBUTION OF THIS THESIS

In this thesis, the different issues of a web digital library are identified and multi-agent based solutions are proposed to solve those problems.

The key contribution of this thesis can be summarized as follows:

1. Various software tools used for the design and development of intelligent agents are identified.
2. The problems of dynamic optimal content allocation (NP-Hard) in the real time hierarchical network system as well as the Partially Observable Markov Decision Problem are identified. Also, design and development of a multi-agent based user access pattern system to solve this problem is an innovative step and is exhibited through a simple simulation experiment.
3. It is identified that the design and development of domain-specific component increases the performance of the system. This is proved through the intelligent agent proxy design and simulation experiments. Specifically increasing the content and user semantics knowledge in the design of the proxy enable the system to have a high-hit ratio is another innovative step.

4. A new multi-agent based concept patterned classification and retrieval/recommendation system is designed and developed and this enables one to solve the problem of distributed text classification and retrieval. Dynamically adapting the user by building the dynamic user profile to give relevant retrieval/recommendation is yet another innovative step in web digital library.

1.5 ORGANIZATION OF THE THESIS

In these previous sections, the characteristics and nature of multi-agent systems, architecture, problems and issues of web digital libraries and the need for multi-agent system based solutions to digital libraries were discussed. The rest of the thesis is organized as follows.

In Chapter 2, a summary of agent characteristics and nature, agent paradigms and software tools used for development and deployment of such systems is provided. A unique methodology for the literature survey is chosen. In this thesis we have addressed four different problems of web digital libraries and therefore a simple review of all these problems and issues are explained.

In Chapter 3, a multi-agent system based user-access patterned optimal content allocation method for web digital libraries is presented. Unique distributed algorithms to compute the optimal cost taking into account the
bandwidth and storage and a system design and sample experimental results
are also presented.

In **Chapter 4**, an intelligent-agent based user-access patterned proxy
design method for digital libraries is presented. Unique alternative approach
for application proxy design method specifically for digital libraries is also
presented. In this design and experiment it is clearly proved that bringing the
domain knowledge into the rational system component would increase the
performance of the system.

In **Chapter 5**, a multi-agent based domain-specific self-proclamative
hierarchical concept patterned text classification method for digital libraries is
presented. This unique concept matrix representation allows one to represent
the document as a collection of technical phrases. Also, a concept relativity
analysis permits us to classify the documents into appropriate hierarchy. This
development and experiment has exhibited a comparative performance with
the human judged document classification.

In **Chapter 6**, a user adaptive multi-agent based self-proclamative
domain-specific hierarchical concept patterned text retrieval method for digital
libraries is presented. This unique concept matrix representation allows one to
represent the user interest as a collection of technical phrases. Also, concept
relativity analysis and user access pattern learning permits one to retrieve the
documents from the system as per the user requirements adaptively. In this
design and experiment it has exhibited a comparative performance in the user
satisfaction level.

In **Chapter 7**, this thesis is concluded by summarizing the contribution
of the thesis and providing the avenues for further research.