Chapter 1

INTRODUCTION

1.1 Motivation

Semantic Web (SW) is the vision for the next generation of the web that aims to make computers understand the information available on the web pages rather than merely presenting it to the users. The SW intends to transform World Wide Web (WWW) into an intelligent web that not only processes the information for the users but also for machines in such a way that machines can interpret and exchange information on the web, thereby, increasing the probability of relevant information retrieval by the end user. The initial waves of semantic web can be realized in the form of changes in web services and ease of internet surfing. However, one major obstacle in implementing semantic web is that machines and people use different ways of lexical processing. Human beings make use of words from the very early years of their lives, thus they are able to draw inferences out of irrelevant and incomplete information, which is not the case with computers. To make computers able to understand meaning of words and relationship between different words, they must have documents describing all the words and logic to make necessary connections. Semantic web achieves this goal through **Ontologies**, where ontology is a document or file that formally defines concepts and their relationships with each other [119],[120]. In effect, it is vocabulary that describes objects and their relationships in a domain.

Semantic web aims towards automation of searching and aggregation of useful information spread across distributed systems. Thus it requires use of instrument which can work autonomously, have learning ability and ability to work cooperatively. Software agents being equipped with these features along with many other appealing attributes suit well to SW applications.
Tim-Berner Lee, who is father of WWW, in his vision of SW [128] very appropriately, emphasized the role of software agents in its implementation. Agent technology has proved to be instrumental in implementation of SW done so far. For instance, *Cooperation* is one of the features which agents are possessed with. As the size of WWW is very large, it can’t be assumed that one agent will be able to extract all information required by the users. Every agent is designed to perform a specific task and in order to provide services beyond it’s capabilities either it communicates with other agents and takes their services or in order to perform complex tasks a group of agents work collaboratively, known as a Multi-agent system (MAS). Again one MAS can’t satisfy the service requirement of all web users, thus different MASs are developed and deployed for providing different services. Each MAS is possessed with its own domain ontology defining terminology and relationship between different concepts. Fig. 1.1 given below illustrates this fact that due to capability of agents to extract useful information from heterogeneous sources, they are employed in transforming WWW into SW.

![Figure 1.1: Agent Community in Generating Semantic Web](image)

### 1.2 Software Agents

The work done in this thesis draws heavily on software agents exploited in the form of MAS, since SW can not be a reality without these systems in scene. The field of agents due to its appealing features has been exploited in many diverse researches,
approaches and ideas, which have turned it into dynamic research areas in recent years. Agent research stems from the work in distributed artificial intelligence conducted in the 1970’s. Carl Hewitt proposed an Actor system [26] where each Actor had an explicit internal state and had the capability to respond to the messages of other Actors. While the subsequent years focused on the more theoretical aspect of bringing intelligence to software by incorporating the budding agent-technology. As a result, the last decade has seen a huge expansion of systems to solve practical problems drawing on advances in object-oriented programming, distributed processing, the Internet, the Web and the increased digitization of information and services. The increased popularity of agents produced many different types of agents such as Belief Desire Intention (BDI) agents [17], weak and strong agents [93], interface agents [74], distributed or multi-agent systems [78], autonomous agents [74] and even emotional agents [150],[65]. Complimenting this list with varied set of domains that agents have been applied to, include military intelligence gathering, industrial production planning, network resource management, robotic football, aircraft maintenance tools, financial portfolio management; and a host of e-business and internet applications such as online auctions, web mining and comparison shopping. Properties like coordination, cooperation, autonomy, rationality, veracity, learning ability and intelligence prove the relevance of agent-based framework for the SW.

1.3 Generations of the WWW

Semantic Web represents the third generation of the web also known as Web 3.0 [101],[66]. Tim-Berner Lee employed in Corporation for Research and Education Networking (CERN) gave the idea of WWW in early 1990 for information exchange. Due to lack of proper technologies and platforms at the time of inception, WWW has taken time to shape from information oriented web to knowledge oriented web. On the basis of developments web is classified in three generations. The first generation of WWW i.e. Web 1.0 was simply an information portal. Web pages

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2 [http://www.w3.org](http://www.w3.org)
created by producers displayed the information about a product or service for the consumers. Consumers could only see what was meant to be seen, they were not allowed to change the contents. Information exclusivity was the feature of Web 1.0, everyone wanted to own the contents deceiving others.

Information was displayed using HTML files, lacking context awareness. Since the information displayed was useful in the context for which it was designed but not in many others, where it could have been used otherwise. Web was more commercialized and participants were mainly companies. Non-scalability of data was another major problem with web 1.0 since there was no standard system for publishing data in such a way so that it could be easily processed by anyone. Lack of interaction for information exchange was the major problem faced by this generation. Also due to lack of search engines, user’s convenience of information access was very low.

In Web 2.0 [49], WWW transferred from information portal to a platform for information exchange. This generation of web is more oriented towards users. Social networking sites and blogs facilitated information exchange between producer-consumers & vice-versa. Search engines like Google changed the way of internet access and its importance in naïve user’s life. As a result number of internet users grew from 45 million in 1996 to 200 million internet users in 2003 [31]. HTML[^3] was replaced by XML [31] and RDFS[^4] making reusability of information easier.

Web 3.0 [101],[66] refers to transformation of Web from a linked document repository into a distributed knowledge base and application platform, thus allowing the vast range of available information and services to be more effectively exploited [64].

It makes use of RDF [66] along with XML to describe the meaning of data being displayed on the web pages and other documents. Unlike HTML that merely describes documents, RDF describes entities or things. It doesn’t emphasize on

[^3]: http://xml.coverpages.org/TEI-GentleIntroXML.pdf
formatting and style of data being displayed rather it explains what the entity under consideration actually is. The underlying aim in development of SW is to return context sensitive information to the user and to automate the process of searching for human users. Fig. 1.2 given below depicts the generations of WWW and various tools employed in each generation.

![Fig. 1.2 Generations of WWW and Tools Used in Implementation](image)

1.4 Challenges in Designing an Intelligent Multiagent Interface for SW

With passage of time agent technology changed into societies of agents called as Multi Agent Systems (MAS). MAS are involved in knowledge extraction and providing services to the users in one way or the others. Increased use of MAS demanded more frequent creation and hence deployment of ontology. Since MAS works collaboratively with other MAS, they need to communicate which becomes very difficult due to difference in ontologies employed by them. In addition to lack of standard communication interface for MAS makes it difficult for agents to communicate, lack of standard ontology mapping mechanism in homogenous and heterogeneous environments is another challenge faced in SW. Communication Security among MAS is also a feature that requires attention since Security stack of SW architecture [15] is not paid due attention. SW applications are relying on MAS working in the background, thus robustness in application/services can only be ensured by guarantying robustness in MAS.
The proposed framework makes use of intelligent multi-agent systems to address above highlighted issues and hence contributes uniquely towards functioning of SW.

1. **Standard Ontology Mapping Interface**

Since SW can’t be assumed without MAS and MAS can’t operate without ontology, therefore Ontology forms the core of SW. Communication among these systems can only be carried out if they either share a common language or are able to recognize the exchanged messages by any other means. Thus ontology mapping is one of the most important challenges faced in SW. Considering the diversity of WWW, the task of mapping is not at all simple. In fact, MAS are not designed for one domain and moreover heterogeneous domains demands diverse terminology. Thus problem of ontology mapping is little easier in case of homogeneous domains but even more difficult for heterogeneous domains.

Ontology mapping can be considered as translating every entity in ontology $O_1$ into some corresponding entity defined in ontology $O_2$. For instance, the concept *tourism_department* can be mapped to *Ministry_of_Tourism* in two different ontologies associated to tourism and travel however the former can be commercial and later can government owned.

In fact, ontology mapping involves varied tasks concerning the alignment [94], articulation and merging of ontologies [117] where ontology alignment refers to establishing a set of binary relations between the vocabularies of two ontologies and ontology articulation involves generation of rules through which fusion or merging of ontologies are being carried out.

Research efforts [153] have already been done towards implementation of ontology mapping mechanisms, however there is no consensus on any one mechanism. Also some techniques developed require human intervention for performing ontology mapping, which is not desired for web based systems.
Solution:

This research presents a framework for mapping of ontologies [13]. In this work a mechanism has been provided which can serve as a layer among communicating MAS. The newly designed multi-agent framework meets the challenges imposed and subsequently has attained the following desired objectives:

- It delegates the ontology mapping task entirely to intelligent agents, leading to automation of mapping process.
- The proposed mechanism provides ontology mapping for both homogenous and heterogeneous fields/domains.
- Ontology extension feature exploited in this framework, allows it to extend ontology when a new concept arrives initially for mapping. Thus with passage of time, primarily designed ontologies become richer, reducing delays in mapping.

2. Establishing Trust among MAS working in SW

Multi-Agent Systems involve interactions of autonomous agents to provide desired services to their users. This flexibility of providing services to users raises significant security challenges [68] for the agents participating in communications. Contract Net Protocol (CNP) [158],[69] is standard communication protocol provided by Foundation for Intelligent Physical Agents (FIPA). Although CNP address most of the issues related to agent communication but it doesn’t pay any attention towards establishing trust among communicating counterparts, which is very essential for MAS working in open, dynamic and heterogeneous environments. Although some variations of CNP has been proposed in literature but none has focused on this aspect. Researchers have focused on encryption of mobile agent code and communicated messages for ensuring security in agent communication. However complete security can’t be ensured without establishing trust among communicating parties.
Solution:

Concerns about security are actually two fold: one dimension is to check authenticity of the agents prior to starting communication; it is to check whether they are what they claim to be. Secondly, even after their authenticity has been proved, one can’t ensure that communicated message is not vulnerable to attacks without implementing any security mechanism. Thus in order to address above stated issues, this work presents solution for both the dimensions separately to ensure complete security in agent communication.

- As a first step, a secure communication strategy has been proposed by incorporating trust establishment feature in existing standard version of CNP. This new version of CNP is called as Contract Net Trust Establishment Protocol (CNTEP) [7]. It facilitates establishing trust among MAS before initiating communication. Through this protocol, communication will start only if communicating parties are able to prove their authenticity and gain a level of trust.

- In second phase of security, communicated messages are encrypted. Encryption is a well known technique for securing messages in communication. Traditional techniques of encryption employ DH, DSA [76] & RSA ([76],[115]) security algorithms. But these algorithms use very large key sizes, increasing the time and space complexity of encryption algorithms. This research work presents Elliptical Curve Cryptography (ECC) [115],[53] based security engine for semantic cyberspace. Elliptical curve cryptography (ECC) is public key cryptosystem that provides same level of security as provided by traditional security algorithms discussed above, but uses considerably small key sizes thereby reducing time and space complexity of encryption- decryption process.

ECC is an upcoming technique of encryption and researchers have already explored applicability of ECC in wireless security, WLAN authentication and
privacy infrastructure (WAPI) and also in Wireless Transport Layer Security (WTLS). However none has tried to employ it in SW. This work uniquely contributes by employing ECC based security engine [9] for protecting messages in semantic cyberspace.

3. **Adding Robustness to the proposed framework**

MAS serve as backbone of SW, but being software components they are also prone to failures such as processor failure, communication link failure and attack by malicious agents leading to faults in MAS. However, continuous service provision regardless of any failure is the most desired feature of any MAS. Fault tolerance is an approach to increase dependability of an application or system avoiding system failures in the presence of faults [73]. This is also referred to as robustness of the system.

Inherent modularity of MAS produces some extent of fault tolerance in itself but dynamic nature of working environment, non-deterministic nature of agents and lack of central controlling authority in MAS makes it difficult to predict and handle errors well-in-time. Thus the need of introducing robustness in the multi-agent based frameworks is apparent.

Replication of agents is the most commonly used technique for providing fault-tolerance. Replication is basically creating one or more duplicate agents in the system. Each of these duplicates is capable of performing the same task as the original agent. The aim is whenever a component fails; another component shall immediately take the charge without affecting the stability of system and also, continues to provide services to the users with an acceptable delay. However, this process increases the overall complexity of the system and incurs overhead. Replication is classified as active and passive replication. In active replication, the participating agent and its replica processes the input in parallel leading to immediate recovery in case of failure, whereas in passive replication, the inputs are processed by the originally participating agent only,
updating the state of the agent in its replica subsequently. In contrast to active replication which increases the overall complexity of the system and is expensive too, passive replication is cheaper to implement but results in delays while recovering the system from failure. Active replication has been employed by most researchers [159],[121],[116],[102],[37] to ensure robustness in MAS. But providing active replication to all the agents in MAS, unnecessarily increases implementation cost and complexity of the system. Thus need for an improved strategy for providing fault-tolerance in MAS is apparent.

**Solution:**

This research work proposes an ‘*Adaptive and Automated Fault-Tolerance for Multi-Agent Systems*’ [8] which provides equilibrium between active and passive replication strategies. The emphasis of this work is that all the agents employed in a system don’t have same importance for the overall working of the system. Thus instead of having active replication for all the agents, system shall have active replication for more critical agents and passive replication for lesser ones. In order to have an effective fault tolerance strategy, system should have an appropriate mix of active and passive replication. This strategy not only, shall provide optimal utilization of system resources and reduce system complexity but also should lead to optimal fault tolerance for the system.

1.5 **Organization of the Research Work**

The thesis has been divided into seven broad chapters as listed below:

**Chapter 2:** This chapter provides the insight of Semantic Web and also elaborates software agents along with its architectural details and highlights the areas which still require attention of researchers.
Chapter 3: A detailed review of the literature on the role of intelligent agents and its applications in the field of Semantic Web has been provided. The survey done highlights the major issues and disputes prevalent in the field of SW.

Chapter 4: In the light of the issues highlighted in chapter 2, 3 and 4, the raison d’être of a new agent-based framework known as Design of an Intelligent Multi-agent Framework for Semantic Web has been proposed [20]. A discussion about various layers and algorithms required for the working of agents has been provided. It illustrates the proposed multi-agent framework in step-wise manner with the help of additional service providing features. Besides, it presents the design of a secure communication strategy “Contract Net Trust Establishment Protocol” [7] for establishing trust among communicating counterparts prior to start of communication. Also, a framework for “Elliptical Curve Cryptography based Security Engine” [9] has been proposed. Further the design of “Automated and Adaptive Fault Tolerance for MAS” [8] is also presented to ensure robustness in the proposed framework.

Chapter 5: The performance of proposed agent-based framework [20] has been evaluated and compared with the metrics available in literature.

Chapter 6: It concludes the outcome of the work. It also endeavors to explore the possibilities of future research work based on proposed frameworks.