Chapter 1

INTRODUCTION

1.1 Introduction

Software agents (1,2) are the entities that act as an interface for variety of applications such as electronic commerce, search engines, telecommunication, just to list a few (3,4). These soft entities are finding their space electronic world because of their pertinent characteristics such as autonomy, rationality, mobility, temporal behavior, interoperability, intelligence etc. In addition to above mentioned characteristics, the agents can be added animatedly to any agent-based system making the system easily scalable and expandable. In fact, a software agent is a computational entity that can not only recognize its environment but also reason the reaction. An agent in a system can act alone while multiple number agents forming a multiagent system (MAS) (5,6) may opt to work as team members as well.

As compared to objects in an object oriented system which only react as directed, agents in a MAS, communicate and reason with other agents autonomously and can also deny an action. In order to communicate, agents exchange messages using various communication languages more commonly known as agent communication languages (ACL) (7,8). An ACL describes the rules for exchanging messages. Using a common ACL, the communicating agents understand the semantics of messages being communicated and are able to respond coherently to achieve a goal. However; in a distributed system, all communicating agents may not choose to use a common ACL and hence are unable to communicate if these have been designed to perform pre-defined actions only, thus omitting the need of communication. However, different agents (using different languages) can communicate using different methods such as signaling, message passing, plan passing and speech acts. Signaling synchronizes the activities of
agents using semaphores like signals while message passing approach advocates exchanging the messages between agents. It is usually employed by object oriented systems. Further, agents in MAS can coordinate by sharing their plans of actions globally. Speech acts theories have been introduced to add semantics to the statements being exchanged between agents. On the basis of above approaches, various agent communication languages have evolved and are being studied during this research work. Few most popular ACLs are being discussed in the upcoming section in detail.

1.2 Agent Communication Languages

In Multiagent Systems (MAS) (9) number of agents interacts with each other in different moods and behaviors such as cooperative, destructive, competitive etc. For all such type of interaction, agents need to communicate and for making this communication possible, agent communication languages (ACL) came into existence. The primary motive of ACL is to represent a framework where heterogeneous agents can interact and communicate successfully using some predefined semantics (10), An ACL defines the syntax and semantics of messages being exchanged between agents. Summarizing, an ACL facilitates multiple agents to exchange information and knowledge operating in cyberspace. ACL lays foundation on methods such as remote procedure call (RPC), remote method invocation (RMI), CORBA and object request brokers (11). Although the objective of this growth has always been to facilitate communication between two or more entities but with the latest developments not only the communicating entities have become intelligent, their semantic complexity has increased as well, thereby needing a superior communication language. The section reviews and investigates the evolution of languages specifically developed for agent communication.

The in-depth grilling of literature reflects that speech act theory (12), Foundation for Intelligent Physical Agents (FIPA) standardized ACL (13,14) and Knowledge Query
Manipulation Language (KQML) (15,16) have been the most popular agent communication languages.

Speech act theory primarily focuses on the use of natural language by humans to achieve the desired goals. Few examples include ‘Hello’, ‘Goodnight’, ‘Jokes’, just to list a few. It further states that not all utterances may be true but these may reflect some actions. Basically, speech act is the minimal unit used of communication but it certainly has some meaning associated with it. Although speech act theory laid the foundation of communication in artificial world but it offered very limited number of speech acts to be used effectively amongst artificial agents. FIPA extended this list and called speech acts as communicative acts.

FIPA specifies requirement of designing new agents so that the newly designed agents can be easily included into existing multiagent system without disturbing the existing interoperability of the system. FIPA primarily supports the development and management of agent-based systems including the communication and interaction of agents developed by several designers at different locations. In order to facilitate the interoperation, FIPA has developed Agent Communication Language popularly known as FIPA Agent Communication Language (FIPA-ACL). It is based on speech act theory discussed above. In FIPA-ACL, messages are called actions as these messages perform the action. FIPA-ACL defines the protocol for inter-agent communication using communicative acts independent of agent implementing platform.

KQML is a high-level, message oriented communication language and protocol for information exchange and knowledge sharing among agents (17,18). It focuses on an extensible set of performatives to describe the kinds of communication that agents can have. In addition, KQML provides a basic architecture for knowledge sharing through a special class of agents called communication facilitators, which coordinate the interactions of other agents. It is independent of content syntax and applicable ontology. Upcoming section talks about the history of KQML and later presents the latest developments done so far in this area.
1.3 Knowledge Query Manipulation Language (KQML)

KQML is a high-level, message-oriented communication language and protocol for information exchange independent of content syntax and applicable ontology. Thus, KQML is independent of the transport mechanism (TCP/IP, SMTP, IIOP, or another), the content language (KIF, SQL, STEP, Prolog, or another) and also the ontology assumed by the content. KQML follows layered architecture which further comprises of three layers namely, content layer, communication layer and message layer. The content layer has the actual content of the message in the program’s own representation language. Message layer is the core layer of KQML. It encodes message, finds possible interactions with KQML speaking agent, identifies network protocol and supplies performatives (19).

Agents make use of KQML as language to exchange message but these might follow either one to one, handle based or subscription based protocol (20) for establishing the communication. While in One to One Protocol communication is between individual client and an individual server, in Handle Based Protocol in response to the various queries sent by client, server returns an individual handle for every received query. Accordingly, server responds to each query one by one in response to the handle. Subscription Based Protocol makes uses of performatives defined in KQML. Here, the client subscribes to server’s output by opting ask-all performative and server sends indefinite number of asynchronous replies at irregular intervals.

A KQML message is called a performative (21) which actually represents an action or operation to be taken by participating agents on each other knowledge bases. Basically, performatives are the keywords for establishing interaction amongst KQML agents. In fact, protocols such as contract net protocol and negotiation protocol are based on these performatives. Historically there exist 36 performatives and few updates had been suggested so the figure is now extended (16,17,18,22,23). The set of performatives forms the core of the language. It determines the kinds of interactions one can have with a KQML-speaking agent. The primary function of the performatives is to identify the
protocol to be used to deliver the message and to supply a speech act that the sender attaches to the content.

A facilitator is a special class of agent that performs various communication services like maintaining a registry of service names, forwarding messages to named services, routing messages based on content, providing matchmaking between information providers and clients, and providing mediation and translation services.

During the initial year of developments of KQML, only informal and partial semantics were defined. Since then, researchers have been putting efforts to provide a formal semantics such as introduction of preconditions, postconditions, and completion conditions for each performative (24,25) (see figure 4). For a sending agent (agent_s) and receiving agent (agent_r), Preconditions (Pre(s) and Pre(r)) define the necessary conditions that two communicating agents (agent_s and agent_r) must satisfy before sending and receiving any performative. If the preconditions are not found to be true, error or sorry performative is sent as response. In contrast to above, postconditions (Post(s) and Post(r)) define the state of the sender and receiver after successfully sending and receiving the performative respectively. Alike preconditions, postconditions are also assumed to be true unless a sorry or an error is dispatched reporting the unsuccessful processing of the message. The third condition i.e. the completion condition indicates the final state i.e. the aim with which communication has been initiated had been achieved.

However, to the best of our understanding, the third condition i.e. the completion condition shall be indicate twin state i.e. success and failure. Conventionally, as mentioned above, the completion condition indicates the success of communication and the failure of conversation seem to be lacking in the present scenario and can provide future research direction towards improving KQML. Here, we suggest that exclusive failure state should be present and hence error message or request for retransmission shall be generated. Also, preconditions only indicate the state of the agents participating in communication and do not guarantee the successful execution of performative.
Similarly, the postconditions represent the states of the agents assuming the successful execution of performatives. Further, since agent based computing was treated to be more based on social agency model rather than mental agency model, therefore, performatives or semantic descriptors pertaining to mental attitude seems to be absent from the existing set of performatives and can be worked upon. Work presented in (17,18,24,25,26) indicates that research efforts had been ongoing to improve semantics of KQML. For instance, authors mention that while preconditions are not mandatory for a receiver, it is important to ensure that postconditions are satisfied for the sender. A completion condition indicates the final state, after possibly a conversation has taken place and the intention associated with the performative that started the conversation is fulfilled.

As mentioned in the previous section that only limited number of performatives have been defined so far which lays the foundation of agent communication in a MAS. In fact, very few performatives related to security of messages in KQML exists. Very recently (23) addressing the security need have been proposed but credibility of the proposed model has not been proved. Further, mechanisms related to finding the state of agent are also lacking. Hence, there is an ample scope to improve the existing set of KQML. It can be improved either by adding new performatives, adding new parameters or creating new ontologies. Despite the fact that researchers associated with agent community have been putting efforts to improve and develop new mechanisms to ease the communication and conversation between heterogeneous agents, still there exist challenges pertaining to communication as mentioned above.

Although efforts had been put to strengthen the communication between natural and artificial entities but the involvement of indirect speech acts has demanded more and more research. As a result of these research efforts, KQML has evolved as one of many languages facilitating the agent communication. Available literature suggests that during initial years of development, KQML only had an informal and partial semantic description and still not many commercial applications using KQML are available. Moreover, evolution of FIPA-ACL (FIPA standardized ACL) has declined the use of KQML. Both KQML and FIPA-ACL share similar syntax but are different in terms of
semantics. For instance, KQML message is communicated using performatives whilst the later one makes use of communication acts. However; in both cases agent are required to be committed to achieve the target or complete the delegated task. Further, both the languages have diverted from fulfilling the requirements of researchers and developers working in the domain of Internet technologies. On the other hand, XML has silently provided a platform to intelligent agents and electronic commerce and hence is proving very useful. Further, to the best of our knowledge and literature grilling advocates that development in agent communication language and KQML in particular, has not been the prime agenda of organizations. On contrary XML and the Resource Definition Format (RDF) seem to be strong candidates for replacing KQML even at the syntactic level.

Next section discusses the issues still prevailing in making KQML as more convenient to use. It also highlights the recent developments being carried out to improve the existing structure of language in focus. This section has emerged with the experience of practitioners using KQML as an agent communication language as well as protocol.

1.4 Research Issues

One of the primary issues towards the practical implementation of KQML as a popular ACL is the gap between the semantic theory and theory of agency where the former is primarily based on speech acts and FIPA-ACL considers belief, desire and intention (BDI) architecture as foundation (27). In fact, in contrast to FIPA-ACL which assumes BDI architecture for communication, KQML is based on assertions derived from virtual knowledge base. Initial presumptions about the behavior of KQML were weak but with the introduction of preconditions, postconditions and completion conditions, KQML has proved to be semantically comparable with FIPA ACL. However, conditions related to failure and ensuring the sincerity are missing. It is presumed that an agent would never assert anything that it believes that it can’t achieve but according to the mental agency, it
is highly impractical as agents might deceive the other agents and pose a behavior which semantically it is not expected to behave. It is clear from the literature that some work (28) has been done to improve the semantics of communication languages but since the semantics of KQML are based on mental agency and agents are programmable entities, therefore verification of how an agent is interpreting the message is hard challenge and leads to gaps between theory and practice. There exist only one work of Vieira et al. (29) that addresses the issue of verification of semantics. Further, semantics defined so far are neither unique nor unambiguous. Therefore the desire to put in efforts in this direction is highly apparent. Further, mechanisms related to finding the state of agents are also lacking.

Turning our attention to the available set of communicative acts defined for ACL, it is obviously understood that the set contains very limited number of acts for communication. At the time of listing, the available communicative acts are insufficient and the important acts reflecting the commitments, sincerity, security etc. shall be included with properly defined semantics.

In short, we can summarize that there is an ample scope to improve the existing KQML. It can be improved either by adding new performatives, adding new parameters, and defining basic ontologies, their query answering capabilities and requirements and policies for communication and so on. We aim to improve the same in future.

### 1.5 Aim of the Work

Considering the above stated issues, following is the aim of current research work:

- To Study and Compare KQML with other popular agent communication languages.
- To study the existing agent interaction protocols and explore the feasibility of improvement or requirement of new protocol.
• To propose a novel KQML based agent communication protocol having new set of performatives.

• To improve the existing structure of KQML by involving new set of performatives and also introducing new parameters making existing performatives more functional and capable.

1.6 The Proposed Solutions

The proposed work is being accomplished in four parts as delineated below:

• Comparison of Knowledge Query Manipulation Language with existing ACL

KQML has been one of the early agent communication languages put forward by DARPA and later FIPA-ACL, proposed by Foundation of Intelligent Physical Agents had evolved in competition to KQML. The two languages while different are also similar in many aspects. For example, KQML primarily depends on performatives whereas FIPA-ACL is based on speech-act theory. Further, development of Extensible Markup Language (XML) has outperformed both KQML and FIPA-ACL. However; many MASs are still making use of KQML for agent communication and the need to bridge the gap between system using other communication languages such FIPA-ACL, XML, SQL and so on is highly apparent. This objective recaps the principles behind origin and development of Knowledge Query Manipulation Language and also compares and contrast KQML with FIPA-ACL. It also unfolds various issues in applying KQML as an agent communication language and efforts that are required to improve the existing structure so that it can continue to dominate as a primary communication language. The study summarizes the developments in terms of syntax, performatives, semantics and the working architecture of KQML.
• **A Comparative Study of Popular Agent Interaction Protocols**

Although agent communication languages have played a vital role in facilitating the communication amongst agents operating in a multiagent system; However, the agent interaction protocols also contributes significantly as these allow performatives to be used in systematic manner. The study presents various agent interaction protocols justifying the use of communicative acts as well as performatives during a conversation. An effort has been put to understand the contribution of existing protocols and the limitations therein with the intention to find the scope of new protocol.

• **KQML-based Communication Protocol for Multiagent Systems**

The premise of this objective is to design a communication protocol for the agents operating in different multiagent systems. The protocol thus proposed offers full autonomy to agents for deciding if they are interested in communicating and collaborating with peer agents. It emphasizes that an agent in communication can be in any of the five states i.e. active, acquire, busy, waiting, sleep. The work proposes six iterative rules for establishing the communication and five new performatives in KQML to support the working of protocol in multiagent systems using KQML as communication language.

• **Updates in Knowledge Query Manipulation Language**

Knowledge Query Manipulation Language (KQML) is a language that facilitates communication and interoperability among coordinating software agents. The existing specifications of KQML focus on perspective, meaning, syntax, semantics, coverage and context of communication to lead to the final result derived from the communication. It is desired that the new extension should support the abstract interaction among software agents coordinating in multi-
agent systems. Further, literature reveals that standards that are implementation
independent are also lacking. Therefore, the language which is normative and
can make communication between heterogeneous agents operating cross-
platforms compatible has always been the area of interest to scientific
community. In particular, this premise of this work is to extend pragmatic
component of KQML which would shore up the use of language as a protocol.
Also, the implementation prototype of the proposal is being presented.

- **Assessment KQML- Improved**

The primary contribution of the objective was to explore the metrics for
evaluating an agent communication language. In fact, to the best of our
understanding, literature grilling did not reveal many works suggesting the
metrics and further evaluation of agent communication languages. Therefore, a
detailed discussion pertaining to the desirable features of agent communication
language and thus the metrics of evaluation was presented. Later a comparison of
basic KQML with the KQML Improved is being given and it can be concluded
that although the basic KQML still forms the backbone of KQML Improved,
However; KQML Improved contributes significantly in terms of new
performatives, parameters as well as a communication protocol.

1.7 Organization of Thesis

This thesis is divided into eight broad chapters as listed below:

*Chapter 1* provides an introduction to research work. It outlines the drive to carry
out the research work. It also presents an overview of the proposed solutions to
the stated objectives.
Chapter 2 presents the details about software agents. It justifies the need of agent communication languages. A detailed description about various popular agent communication languages is being given in the chapter. It also highlights the issues pertaining to practical implementation of KQML.

Chapter 3 details the related work in the field of agent communication languages with special emphasis on developments in KQML. The chapter indicates that much work has been done on the domain. However, ample scope is still there to improve the structure of KQML and make it more practical.

Chapter 4 explains the research issues considered during the research work and also presents the objectives thus attained during the course of research.

Chapter 5 mentions the research methodology adopted to achieve the stated objectives. This chapter also enlists the simulation tools employed for implementing the proposed improvements.

Chapter 6 presents the proposed work. It is divided into sections. Section 1 presents a novel protocol titled “KQML-based Communication Protocol for Multiagent Systems” It proposes five new performatives representing the state of agents. It also demonstrates clock synchronization algorithm for synchronizing the exchange of messages. Section 2 is about “Updates in Knowledge Query Manipulation Language” which proposes new parameters suitable enough to ensure the quality of service. The chapter emphasizes that agent communication should be quick and must follow temporal constraints and hence parameters ensuring temporal constraints along with quality of response has been proposed in this section.
Chapter 7 presents the evaluation of the proposed work. It compares the improved version with the existing version. The improvement thus suggested contributes significantly towards the research.

Chapter 8 finally concludes the thesis and highlights the future scope of research work. It also gives future research directions.

1.8 Conclusion

The chapter provided insight into the motivation of carrying out the research work. It illustrated agent communication languages and KQML, in particular. A short summary regarding the proposed solutions of the highlighted challenges was also presented and finally the chapter concluded by presenting the structure of thesis.

Next Chapter in detail describes the various agent communication languages demonstrated in literature.