A Review on Agent Communication Language

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Abstract. Agent technology is a new emerging paradigm for software systems. In order to fully utilize the capability of this technology, multiple agents operate in software environment by cooperating, coordinating or negotiating with each other. However, these interactions require these agents to communicate with each other through a common language or protocol. Agent communication language (ACL) is a vital component in multiagent system (MAS) to enable the agents to communicate and exchange messages and knowledge. However, there are no universally agreed agent communication language that is widely adopted. Different agent communication languages and different semantic models have been developed to ease the communication between agents in MAS. The purpose of this paper is to review and highlight advances in the development of ACL.

Keywords: Agent Communication Language, KQML, FIPA-ACL, Mentalistic, Conversation Policy, Social Commitment

1 Introduction

Agent technology is a new emerging software paradigm that possesses certain characteristics that are suitable for computing environment which are highly heterogeneous, distributed and complex. To date, there is no universally agreed definition for what is an agent. There are many definitions used by different researchers to define agent in different research contexts. Genesereth [1] defined software agent as software component that is capable of exchanging knowledge and information. Bradshaw characterized software agent based on ascription and description. In ascription, software agent is defined based on its attribution and family resemblance whilst description software agent is defined based on a set of attribute list [2]. Nwana classified software agent into topology based on three primary intersect attributes which are cooperate, learn and autonomous [3]. Wooldridge defined agent as an autonomous software entity that is situated in some environment where it can monitor and response to changes proactively or reactively by itself or through communication with other agents to persistently achieve certain goal/task on behalf of user or other agents [4]. In [5],

R. Alfred et al. (eds.), *Computational Science and Technology*, Lecture Notes in Electrical Engineering 481, https://doi.org/10.1007/978-981-13-2622-6_47

agent definition is further distinguished between strong notion of agent and weak notion of agent. A weak agent is said to possess primary properties such as autonomy, reactive, proactive and social ability. Besides primary attributes, agent may also possess some of the secondary attributes such as benevolent, sincerity, rational, learnability and others. On the other hand, a stronger notion of agency is defined as possessing the mentality attitudes such as beliefs, desire, intentions and others. Hitherto, it can be observed that there is no single widely accepted definition of what is an agent. Nevertheless, there are some common properties that can be derived from these definitions such as agent is autonomous and it can communicate in order to exchange information. However, a single agent computation power is still limited to solve a large complex system which are decentralized and distributed.

In order to realize complex systems, the capability of a single agent is never enough. Thus, multiple homogeneous or heterogeneous agents are required to scale up for large, distributed complex systems. A system where multiple single agents work together is referred to as multiagent system (MAS). As mentioned MAS consists of multiple agents which may have common goal where they work together to achieve a certain task; or have self-interested goal where each agent competes against each other for resources; or they are required to coordinate to achieve a certain task. The advantages of MAS include scalability, efficiency, robustness and reusability [5]. However, in order to realize the interaction such as negotiation, cooperation, collaboration and coordination between agents, a common language protocol is required in order to achieve interoperability. These interactions can only be carried out if the agents can communicate and understand the communicated message syntactically and semantically.

Thus, agent communication language has been developed in order for agent to communicate with each other and understand the content of communication. In the next section, several existing agent communication languages will be discussed.

2 Agent Communication Language

Agent communication language (ACL) is a high level abstraction method for agent to exchange information and knowledge [1]. ACL allows more complex knowledge exchange such as plans, agent's goal, and believes which cannot be exchanged using object-oriented approach. Object oriented approaches such as remote procedure call (RMI), remote method invocation (RMI), COBRA and object broker request are not suitable for agent communication.

Knowledge manipulation and query language is the first ACL that was developed for agent communication [6][7]. It was initially developed as part of the knowledge sharing effort by DARPA with the aim to create a set of reusable tools to transfer and exchange high level knowledge and information [8][9]. Then it evolved to become high-level message oriented communication language between agents to exchange information and knowledge which is independent of the content syntax and ontology. KQML has three layers' organization structures that are composed of content, communication and message layer. The content layer represents the content of the mes-

sage. The communication layer is composed of the message transport layer component such as sender and receiver. The message layer encodes the KQML message which includes wrapping the content and communication layer. The vital component of the message layer is the performatives. Performatives are utterance actions which are based on the speech act theory that denotes the illocutionary meaning of the speaker [10][11]. KQML's syntax is a LISP-like expression that is composed of performatives and pairs parameters and value. During the early development of KQML, there were no particular semantics models that were adopted and this has resulted in several variations of KQML dialect which were based on the application context. As a consequence, KQML has been criticised for its lack of formal semantic model which led to confusion and ambiguity in performatives meaning [12]. Although, KQML allow arbitrary content language, the de facto content language for KQML is the knowledge interchange format [13]. KIF uses the first-order predicate calculus to describe things in knowledge representation. The Ontolingua is used as the ontology for the KQML communication [14]. Labrou and Finnin deviced a semantic model for KQML based on precondition, post condition and complete condition of mental states [15][16][17]. However, this mentalistic notion suffers certain drawback which will be discussed in Section 4.

FIPA-ACL is an agent communication language specification developed by FIPA (Foundations of Physical Agents). FIPA is a non-profit organization formed by various organizations from academics to industry. The aim of FIPA is to develop a set of standards or specification to promote the interoperability of agent technology. To date, FIPA has produced a set of standard specification that needs to be adopted in order for agent to communicate and interact in interoperability mode. Among these set of specifications, one of the specification is called FIPA-ACL specification which promotes the FIPA-compliant agent communication language. The first FIPA-ACL specification was in 1997 and subsequently revised in 1998 and improved in the 2000 specification. [18][19]. The syntax of FIPA-ACL is similar to KQML syntax. The semantic model adopted is based on Cohen and Lévesque [20] which is an enhancement of Sadek's work in Arcol [21]. In FIPA-ACL, the performatives are known as communication acts. FIPA defined a set of communication acts in the FIPA communicative acts library specification which is based on the speech act theory [22]. FIPA-ACL does not constraints the use of new communication acts. However, in order to preserve interoperability, these communicative acts must be agreeable by communicating agents in both syntax and semantic. The semantic of FIPA-ACL is based on the feasibility precondition and rational effect. FIPA-ACL does not limit the content language that can be used but FIPA-SL has become the de facto standard for the FIPA-ACL [22]. FIPA-SL is based on the quantified multimodal logic made up of the belief, desires, uncertain beliefs and intentions modal operators. Other supportive specifications for the FIPA-ACL include FIPA ontology specification and FIPA interaction protocol specification which can be found in FIPA website [23]. FIPA-ACL also suffered several drawbacks such as no standard parser or reasoner for FIPA-SL and was criticised in the used of mentalistic notion [24][25]. The next section will discuss some of the works on ACLs.

3 Related Works

This section discusses some of the works on ACLs in chronological order. Singh [27] discussed the shift of semantic model from mentalistic notion to social interaction. Singh, focused on the possibility the semantic model of mentalistic approach. Agent aren't able uncover the internal state of other agents in computing environment. Hence, the semantic of this model cannot be verified. Thus, it was suggested that the semantic based on social interaction of agent community must be grounded on commitment that is expressed in obligation and prohibition according to society norm. Labrou et al [28] discussed the current landscape of the ACLs the role, origin and concepts of ACLs. KQML and FIPA-ACL were discussed and compared. The application of these ACLs in some of the domain were also elaborated. Kone et al. discussed on the state-of-the-art in ACL [29]. They emphasized on the theory of ACL and discussed some of the pragmatic issue on the implementation of ACLs in the existing models which include KQML, ARCOL, FIPA-ACL, agent oriented programming, open agent architecture, mobile agent communication, and other communication models. Labrou and Finin in another review described pragmatic issues of ACLs such as programming languages, API support, syntax and encoding consideration, services and infrastructures for the ACL and the integration of ACLs with WWW. Steven et al reviewed the issues and challenges of agent communication for open environments [31]. Their review is focused on the agent cities network open environment which is a project in Europe that was used as test bed for agents. Maudet and Chaib-draa provided state-of-the-art in conversational policies and the limitations of this particular approach. These limitations which cover the flexibility and specification were discussed in detail [32]. Chaib-draa and Dignum reviewed the trends in ACLs [33]. They introduced the concept, origin and component of ACLs and discussed the semantic of ACLs in terms of mentalistic approaches and conversational policies. Other important issues such verifications, ontologies and further exploration of semantic of ACLs are also discussed in the paper. Vaniya et al. provided survey on the agent communication language [34] which was mainly focused on semantic and syntax and the implementation of KQML in application.

4 Semantic Model

There are many different semantic models that have been developed for ACLs in order to achieve semantic interoperability. Semantic interoperability allows agent to communicate and understand their communication's message content. There are three primary semantic models that are identified in the development of semantic model for ACL namely mentalistic, conversation policy and social approach. The mentalistic approach defines the semantic of ACL in terms of mental states of agent such as beliefs, desires and intentions. Basically the two dominant ACLs, KQML and FIPA-ACL were developed based on the mentalistic approach in which KQML semantic is based on [15] and FIPA-ACL semantic model is based on [20]. However, the mentalistic approach suffers from the drawback of semantic verifiability which was dis-

cussed in [25][27]. Semantic verifiable states that conformance of semantic model could be determined by an independent observer. Since the internal state of agent cannot be uncovered, the conformance of agent towards semantic model cannot be checked. As a result, the semantic interoperability cannot be achieved.

Conversation policy expresses the meaning of the ACL through the composition of speech acts in terms of interaction protocol [35]. Thus, a fixed structure is determined during the adoption of the policy. The implementation of the conversation policy is using finite state. Nevertheless, this approach has two weaknesses which are the lack of flexibility due to the predetermined structure and the lack of well-defined compositional rule the scalability of protocol extension and merging [32].

Social approach defines the ACL semantic in terms of commitments as normative agent society. The effects of the communication acts depend on how the agent should behave in the interaction based on the norm. The concept of commitment is based on the obligation and prohibition of the agent society and is used as the semantic model [36][37]. Obligation is normally specified using deontic logic, however, there are other representations that can be used as well.

4.1 Mentalistic Approaches

[12] discussed the semantic issues of KQML which emphasized on the lack of formal definition of its semantic model. Without a formal semantic, the communication acts are ambiguous and full of confusion. Hence, the ACL is not semantically verifiable and the expected result cannot be predicted. Due to this deficient, Yannis devised a semantic model of pre-condition, post condition and complete condition which are based on mental attitudes [15][16][17]. The semantic model is based on mentalistic notion of beliefs, desire and intention.

Bretier and Sadek presented a rational agent based on the formal theory of interaction called ARTIMIS (Rational Agent Based on Theory of Interaction implemented by a Syntactical Inference Engine) [38]. The communicating agent is modeled as kernel of cooperative spoken dialogue system which model the semantic of communication in first/multi order modal logic of mental attitudes. The reasoning of the communication is based on the inference engine using a theorem prover.

Carron et al. proposed temporal dimension for agent communication language based on speech act theory in mentalistic notion [39]. They modeled the mental states in terms of BDI model with temporal elements which act as constraints for the agent action. The communicative action was modeled in terms of triple consisting of <Pre condition, Post condition, Perlocutionary effect>.

FIPA-ACL was developed by adopting ARCOL agent communication language's semantic model which was based on the semantic of intention of Sadek [21]. The semantic of FIPA-ACL is enhanced by Cohen and Levesque in [20] which is based on quantified multimodal logic which are belief, modal operators for beliefs (B), desires (D), uncertain beliefs (U), and intentions (persistent goals, PG). The semantic of FIPA-ACL is specified in terms of feasibility precondition and rational effect.

Sanjeev presented a group communication semantic for agent communication languages for group interaction [40]. The work derived the semantic of agent communi-

cation model based on intention and attempt-based semantics. They treated single-agent communication as a special case of group agent communication.

Although the mentalistic approach has been critiqued due to unverifiable semantic, however, it does lay a solid foundation for agent communication semantic model based on modal logic and possible world semantic model.

4.2 Conversation Policy

Pitt and Mamdani proposed a general semantic framework for ACL in terms of protocol [41]. The protocols are specified in finite state in order to define the context of communication thus, limiting the possibility of the communication act which are applicable in the particular conversational state.

Philips and Link proposed a mechanism that can dynamically combined different conversation policies into conversation specification [42]. The conversation specification allows the contextual issues to be handled during agent communication. Different conversation policies applied to a given conversation specification can change the nature of the interaction.

Nodine and Unruh describe the implementation of conversation policies in InfoSleuth based on finite-state automata [43]. Two mechanisms which are the extension and concatenation were used to simplify the construction of conversation policy. Besides that, a sharable mechanism was introduced to allow the sharing of conversation policy.

Ahn et al. utilized a handshaking mechanism to construct the conversation policy agreement [44]. This approach allowed ad hoc re-implementation of conversation policy in a dynamic changing computing environment.

Despite the disadvantages aforementioned such as rigid structure and format, conversation policy and interaction protocol does give a verifiable semantic model based allowable sequence of message exchanges.

4.3 Social Approaches

Singh presented a social semantics of ACL based on social commitments and temporal logic [26]. The social commitments are based on social context and meta-commitments and are used to capture the legal and social relation between agents. The commitments in semantic model are expressed in terms of deontic concept. Computational tree logic is used to represent the branching time logic in this semantic model.

Colombetti proposed an approach which used agent speech acts and conversations of agent communication language in commitment based approach [45]. This commitment approach is based on social notion. The important components of the commitment based approach are conversational pre commitment and conversational contracts.

Torroni et al proposed an interaction protocol that can be determined by society agent interaction [46]. The semantic model adopted in the communicative act is in terms of commitment which can be expressed in constraints in deontic logic.

Fornara and Colombetti introduced a conditional commitment and precommitment in the social notion based on operational specification within object oriented paradigm [37]. The implementation of operation specification is in an object-oriented approach by the introduction of a commitment class. The conditional commitment is specified with conditional temporal value which at deadline can be active or not. Whereas the pre-commitment will become active after it is accepted by the other agents.

Macro et al presented a logic based social approach communication between societies of agents [47]. There are three important components in the agent society modelling which are the social infrastructure which is responsible for updating the knowledge base, the social organization knowledge base which defines the structure and properties of society such as rules, norms, protocols and social environment knowledge base records the environment data such as events and history. The mental state of the agents in the agent society is defined based on the social effect in terms of obligation and prohibition. Deontic constraints are used to link the events with the obligation and prohibition. Constraint handling rules are used in modelling these constraints.

Federico et al proposed a FIPA compliant goal delegation protocol between agents [48]. It also emphasized that trust element between agents is an important component in goal delegation. Several security methods were proposed for enforcing the trust between agents. New performatives were proposed in this paper for execution of goal delegation protocol. A validation analysis and sample scenario is carried out in order to show the verification of the protocol semantic.

Benoit et al proposed a novel semantics approach for FIPA-ACL based on semantic social attitudes [49]. The social attitudes is represented with communication attitudes based on the concept of grounding [50][51]. In this work, mental attitudes were represented as public commitment instead of private mental state which is not verifiable. Thus, this approach provides a verifiable, formalized and easily adapted model of ACL.

Guido et al introduced a social networks semantic model for ACL semantic model [52]. The intention of the agent in this model is dependent on other agents in the network which is based on dependence network rather than mental attitudes. The advantage of this model is that it is able to model the conversation based on simple graph-theory which in turn can be utilized by the semantic web community.

Social semantic is current trend of semantic model where it provides a verifiable semantic model based on social interaction in terms of notions such as commitment, obligation, prohibition, norms and others. The future research direction will be mostly based on this model where agents in consider social entity that obliged and commit to the computing environment it participates.

4.4 Hybrid Approaches

Boella et al proposed a role-based semantics for agent communication [53]. The novelty of this approach is by embedding both the mentalistic notion and social commitments into the semantic model. In the mentalistic notion, instead of agent's belief and

goals, the role of agent's belief and goals is used. The role of the agent is also used for commitment towards the agent society.

Dignum and Linder defined a formal framework for agent communication for social agents [54]. The verifiable model is composed of four components which are the information components for knowledge and belief, action component, motivational component for goal and intentions and social component for commitments and obligation. The model has embodied the mentalistic notion, social commitments and other modal operator together into a formal system.

Nickles et al proposed a semantic model for agent communication in terms of ostensible beliefs and intentions [50]. The difference between ostensible beliefs and mentalistic notion of beliefs and intensions are that the latter is based on introvert agent state which cannot be verified whereas the former is based on the opinion of social structure which can be verified. These opinions can be from individual or groups of agents. A weighted probabilistic approach is used to determine the provenance reliability of the opinion.

5 Conclusion

Agent communication is the key component for agent social interaction. It acts as the medium for the agents to exchange high level knowledge and understand these message in order to achieve the common goal or tasks. This paper provides a review of the ACLs that are commonly used which are KQML and FIPA-ACL. Besides that, in order for the agent to communicate effectively, unambiguous semantic interoperability needs to be achieved. As a result, different semantic models have been developed for ACLs. Yet, among these models there is no one agreeable universal model that is agreed by all. Thus, many endeavours need to be carried to reach the consensus. Nevertheless, several properties can be identified from works that have been done. These properties include verifiable, tractable, decidable, temporal elements and others which are valuable insight for the continuous development of agent communication language.

Acknowledgments. This project is funded by the Ministry of Higher Education, Malaysia under RACE0014-TK-2014.

6 References

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