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Gordan Jezic
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Agents and Multi-agent Systems: Technologies and Applications 2019

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Preface

This volume contains the proceedings of the 13th KES Conference on Agent and Multi-agent Systems—Technologies and Applications (KES-AMSTA 2019) which will be held in St. Julian's, Malta, between 17 and 19 June 2019. The conference was organized by KES International, its focus group on agent and multi-agent systems and University of Zagreb, Faculty of Electrical Engineering and Computing. The KES-AMSTA conference is a subseries of the KES conference series.

Following the success of previous KES Conferences on Agent and Multi-agent Systems—Technologies and Applications, held in Gold Coast, Vilamoura, Puerto de la Cruz, Sorrento, Chania, Hue, Dubrovnik, Manchester, Gdynia, Uppsala, Incheon and Wroclaw, the conference featured the usual keynote talks, oral presentations and invited sessions closely aligned to its established themes.

KES-AMSTA is an international scientific conference for discussing and publishing innovative research in the field of agent and multi-agent systems and technologies applicable in the digital and knowledge economy. The aim of the conference is to provide an internationally respected forum for both the research and industrial communities on their latest work on innovative technologies and applications that is potentially disruptive to industries. Current topics of research in the field include technologies in the area of decision-making, big data analysis, Internet of things (IoT), business informatics, artificial intelligence, social systems, health, transportation systems and smart environments, etc. Special attention is paid on the feature topics: agent communication and architectures, modelling and simulation agents, agent negotiation and optimization, business informatics, intelligent agents and multi-agent systems.

The conference attracted a substantial number of researchers and practitioners from all over the world who submitted their papers for main track covering the methodologies of agent and multi-agent systems applicable in the smart environments and knowledge economy, and four invited sessions on specific topics within the field. Submissions came from 15 countries. Each paper was peer-reviewed by at least two members of the International Programme Committee and International

Reviewer Board. Thirty-one papers were selected for oral presentation and publication in the volume of the KES-AMSTA 2019 proceedings.

The Programme Committee defined the following main tracks: agent communication and architectures, and multi-agent systems. In addition to the main tracks of the conference, there were the following invited sessions: agents and MAS applied to well-being and health, business informatics, MAS in transportation systems and agent-based modelling and simulation.

Accepted and presented papers highlight new trends and challenges in agent and multi-agent research. We hope that these results will be of value to the research community working in the fields of artificial intelligence, collective computational intelligence, health, robotics, smart systems and, in particular, agent and multi-agent systems, technologies, tools and applications.

The Chairs' special thanks go to the following special session organizers: Dra. Maria del Rosario Baltazar Flores, Instituto Tecnologico de Leon, Mexico; Prof. Arnulfo Alanis Garza, Instituto Tecnológico de Tijuana, Mexico; Prof. Hiroshi Takahashi, Keio University, Japan; Prof. Setsuya Kurahashi, University of Tsukuba, Tokyo, Japan; Prof. Takao Terano, Tokyo Institute of Technology, Japan; and Dr. Mahdi Zargayouna, IFSTTAR, France, for their excellent work.

Thanks are due to the Programme Co-Chairs, all Programme and Reviewer Committee members and all the additional reviewers for their valuable efforts in the review process, which helped us to guarantee the highest quality of selected papers for the conference.

We cordially thank all authors for their valuable contributions and all of the other participants in this conference. The conference would not be possible without their support.

Zagreb, Croatia — Gordan Jezic
Edinburgh, UK — Yun-Heh Jessica Chen-Burger
Zagreb, Croatia — Mario Kusek
Karviná, Czech Republic — Roman Šperka
Poole, UK — Robert J. Howlett
Canberra, Australia — Lakhmi C. Jain
April 2019

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Part I
Agent Communication and Architectures

Enforcing Social Semantic in FIPA-ACL Using SPIN

Kim Soon Gan, Patricia Anthony, Kim On Chin and Abdul Razak Hamdan

Abstract Agent technology is an emerging software paradigm for developing open, distributed and heterogeneous complex system. There is a need for different software to communicate with one another in order to achieve its task. Therefore, a standard protocol is required. In agent technology, this common protocol is referred to as agent communication language. Agent communication language is a high-level protocol/language that allows agent applications to exchange, parse and understand the meaning of the exchanged content. One of the widely adopted agent communications is FIPA-ACL. An ontology for FIPA-ACL has been developed in previous work. However, the developed ontology does not incorporate any semantic model. Hence, in this paper, SPIN notation is used to model the social semantic of FIPA-ACL as it is able to link the class definition with SPARQL queries to capture rules and constraints to formalize the expected behaviour of classes.

Keywords Agent communication language · FIPA-ACL · Social commitment · Semantic web · OWL · SPIN

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1 Introduction

Agent technology is an emerging software paradigm that provides agent abstraction for developing open, distributed and heterogeneous systems that match with today's Internet application environment [1]. The four main characteristics of agent are autonomy, proactive, reactive and social [2, 3]. Autonomy implies that an agent can execute the program and make decision without or with minimal user intervention. Agent exhibits a proactive behaviour in a goal-directed action based on their design objective. Agent reacts appropriately to environmental changes in a timely fashion. Agent is also able to communicate using high-level information such as mental state and plan instead of a simple low-level message passing [4]. There are other attributes of agent systems such as rational, learning, benevolence and others. However, these attributes are dependent on the application domain. Agent exhibiting these attributes is considered as a weaker notion of agency. Stronger notion of agency states that besides these attributes, an agent should be endowed with mental attitudes such as belief, desire and intention.

In order for the heterogeneous agents to communicate and understand each other, a standard communication medium is required. Agent communication language (ACL) is the standard communication medium that plays a vital role in multi-agent system interaction [5, 6]. There are two popular ACLs that are widely adopted which are the FIPA-ACL and Knowledge and Query Manipulate Language (KQML). KQML is the first ACL developed by DARPA through the knowledge sharing effort [7–9]. KQML adopted KIF as the de facto for content language and ontolingua as the ontology service [10, 11]. One of the unique features of KQML is the implementation of facilitator which acts as an agent mediator. FIPA-ACL is an ACL developed by FIPA which is a non-profit organization established to promote agent technology and increase interoperability between multi-agent system through devising sets of standard specification [12–14]. Although FIPA-ACL is similar to KQML, it is more popular than KQML due to the official body that governs the evolution of FIPA-ACL and the adoption of formal semantic in FIPA-ACL.

There are three main components that contribute to each ACL; these are the syntax, semantic and pragmatic. The syntax is the grammar rule used to parse the ACL for further processing. The semantic is the information processing to achieve the uniform understanding between the communicating agents. There are three semantic models adopted in ACL which are mentalistic approach, conversation policy and social semantic. The mentalistic approach is based on the mental attitudes such as belief, desire and intention. The conversation policy approach is based on the interaction rules list for each interaction to be carried out [15]. The social semantic is based on the social interaction between agents in terms of norm and commitments [16, 17]. The social semantic emphasizes the commitment from a debtor towards a creditor in promising or agreeing to complete on some tasks during the interaction. The social semantic is more popular because it reduces the limitation in mentalistic (unverifiable) and conversation policy model (complexity in combining rules). The third component of ACL is pragmatic, which is the ease of adoption of ACL in real-world environment.

Many techniques and methods have been used in order to achieve the interoperability of ACLs including conceptual structure and object constraint language. Another emerging trend is to use semantic web technologies. Semantic web (SW) encodes the web content as promoted by W3C [18]. The SW is an extension of the current web by encoding the web content with well-defined meaning that is machine processable [19]. A set of standards such as RDF [20], RDFS [21], OWL [22], SWRL [23] and SPIN [24] have been created to realize the semantic web. There is an increasing trend in applying semantic web into multi-agent system to increase automation, computation efficiency and enhance the communication of ACL. SW enables accessibility of the encoded knowledge and increases the utilization of the knowledge for computing. Therefore, representing the ACL with SW technologies enables the encoded knowledge to be exchangeable and processable between agents. In addition, this allows different agent applications to reuse existing knowledgebase in SW (such as DBpedia).

In previous work [25], a FIPA-ACL ontology was developed to enhance the interoperability between MAS. FIPA-ACL ontology encodes the knowledge and vocabulary required to utilize the FIPA-ACL as communication medium in MAS. This work will extend the FIPA-ACL ontology by incorporating SPIN notation in enforcing the FIPA-ACL social semantic integrity constraint. SPIN is an industry standard to represent SPARQL rules and constraints on semantic web models [26]. Therefore, it can be used to represent the rules and constraints to enforce the social semantic integrity constraints. Moreover, SPIN's object-oriented features made it possible to define reusable functions and templates. An example of a social semantic integrity constraint is assigning the different communicative acts to the sender and receiver of the message to take up the roles of debtor and creditor in a conversation. In this case, a debtor is committed to fulfil certain commitment towards the creditor. In this situation, SPIN can be used to represent this kind of rule which will be attached to different communicative act classes.

2 Related Work

In this section, some of the related works in ontology-based FIPA-ACL are reviewed to serve as the foundation and motivation of this research. This review is organized in chronological order to observe how the researches in this area have progressed over time. One of the earlier works by FIPA is on its specification to encode the content of the message in RDF encoding known as the FIPA RDF Content Language Specification [27]. This specification specifies how to represent objects, propositions and actions in RDF and in different RDF versions with different extensions. The motivation for encoding in RDF is to increase the level of interoperability. The advantages of RDF encoding include extensibility, reusability, simplicity and standards for data and schemas exchange. However, RDF is just a data format for encoding and exchange, and so its expressiveness is limited. For example, RDF is unable to specify the OWL constraints such as cardinality and the type of properties.

Another semantic web technology, DAML, has also been proposed to encode the ACL message [28]. The richer expressivity of DAML compared to RDF and RDFS enriched the content expressed in the ACL message. In this work, a DAML ontology is defined for communication between agents. A demo application of ITTalks project was used to illustrate the communication encoding in DAML. Unfortunately, DAML as a cornerstone of OWL did not gain momentum as semantic web technology. Zou continued his research effort in ACL using semantic web language as content language but this time he focused on OWL. Travel Agent Game in Agentcities (TAGA) is a FIPA-compliant framework that extended and enhanced Trading Agent Competition (TAC) scenario in Agentcities as an open MAS environment. OWL was used as the content language in FIPA-ACL messages for agents to communicate with each other and reason about the action and services. By utilizing the benefits of OWL, the content of the message can be more expressive, unambiguous, computer-interpretable, and interoperable, and has automated reasoning techniques, higher level of interoperability between agents and meaningful content can be shared [29, 30].

AgentOWL is another research that incorporated OWL as representation for agent internal model and communication [31]. It is a MAS-distributed framework that is built on top of JADE with a generic knowledge model for agent. Formal description of the model is represented using description logic. There are five main elements in the model including resources, actions, actors, context and events. AgentOWL used Jena semantic reasoner to reason the context, resource, action and knowledge domain of the agent and content of agent communication. CommonKADs is used to model and develop the MAS and the UML, and AUML modelling languages are used for modelling formalism. As a result, the agent knowledge model is more generic and expressive and can be easily adopted and used in other similar applications.

Pu used semantic web representation for negotiation protocol in electronic commerce [32]. Ontology was used to describe the negotiation protocol to increase the efficiency of the negotiation process. The negotiation protocol used in this research was the contract net protocol. The prototype demo was built on top of JADE and the reasoning used Jena API. This work was further extended using OWL for the agent communication process in a layered architecture.

Semantic agent model (SAM) used semantic web technologies in MAS modelling and knowledge base support [33]. In SAM, semantic web rule language (SWRL) was used in modelling the behaviour and constraints of different agents. A three-layered architecture was used to model the agents which was made up of a knowledge base layer, an engine layer and a low-level action layer. The different states of agent actions were modelled using extended FSM concept.

Fornara was one of the important key players in representing ACL social semantic model using obligation and norms [34, 35]. An obligation ontology was developed to model the obligation between debtor and creditor in temporal proposition. An external program was used to keep track of the temporal constraints in the temporal proposition to determine the different states of the obligations. Fornara and her team further extended the research to study the representation of policy and artificial institution [36, 37].

It can be observed that there are some ongoing works in ACLs. However, none of these has used SPIN in the modelling of FIPA-ACL. SPIN's ability to attach the SPARQL rules and constraints to class definition is suitable in enforcing social semantic integrity constraints to different classes of communicative act. Hence, in this research, the SPIN notation is used in the FIPA-ACL modelling.

3 SPIN

SPIN stands for SPARQL Inference Notation. SPARQL is the querying protocol and language used to query the RDF data. RDF is basic data format in the SW stack to encode information to facilitate information exchange and processing. SPIN is a de facto industry standard used to represent business rules and constraints in SPARQL RDF. SPIN is based on combination of object behaviour of object-oriented paradigm, query language and rule-based language. The key idea of SPIN is to link class definition with SPARQL queries to capture rules and constraints to formalize expected behaviour of classes. SPIN architecture is based on layering framework which consists of three layers. The first layer is the SPIN SPARQL syntax which is composed of RDF vocabulary for queries. The second layer is the SPIN Modelling Vocabulary which is composed of rules, constraints, function and templates. The third layer is the SPIN Standard Modules Library which is composed of different reusable modelling constructs of the function and templates mechanism. SPIN provides vocabulary for representing SPARQL queries using RDF triples. It provides a meta-modelling capability to define SPARQL functions and different templates. The main advantage of SPIN is its ability to store SPARQL queries together with the domain ontology model which can be easily shared on semantic web. It also allows referential integrity between ontology concepts and manages namespaces only once. SPIN implements constraints through spin: constraint property to link class with SPARQL queries formalizing invariant for class member. SPIN implements rule through spin: rule property to link class with SPARQL CONSTRUCT queries to define inferences for class member. Further, SPIN allows SPARQL function to be defined using spin: Function where the SPARQL queries are used in spin: Function body. SPIN function can modularize and extend SPARQL in a declarative manner and store it as RDF. The expressiveness of SPARQL is further extended through recursion. SPIN allows all the above queries to be stored in reusable form through spin: Template where it wraps SPARQL queries into reusable building blocks by instantiating them with arguments. This is done through industrial-strength RDF APIs implementation which runs directly on RDF data. SPIN enables the computation of property values from existing properties. It can initialize resource values with either a default value or compute values. It also allows set of rules being isolated to execute in different conditions. SPIN supports incremental reasoning where reasoning can take into account new assert information. These templates allow user to define rules in high-level domain. SPIN can be used to check the validity of data through constraint checking. The constraint checking operates with closed-world reasoning and automatically raise inconsistency flags. The templates for constraint checking are implemented using ASK and CONSTRUCT templates. ASK query can be used to return Boolean query results and CONSTRUCT query can be used to construct new RDF from the query result. SPIN also provides a list of common functions in a library. The different rules and constraints bound to FIPA-ACL ontology are discussed in the next section.

4 SPIN Rules for Agent Communication Languages

In this section, the SPIN rules and constraints are used in combination with FIPA-ACL ontology to enforce the social semantic integrity constraint. Different SPIN rules and constraints are linked to different classes of communicative act in the FIPA-ACL ontology. Besides, SPIN rules and functions are used to automate the social semantic for message exchanges between agents.

One of the rules attached to Message class is a rule to infer debtor and creditor agent of a commitment based on the sender and receiver of a particular communicative act type is shown in Fig. 1. The commitment object is based on the conversations between agents in order to assign the debtor and creditor. The rule will receive the argument of message communicative act. Hence, this rule will infer the commitment debtor and creditor based on the communicative act.

CONSTRUCT can also be used in spin: constraint to raise flag for inconsistency in the ontology. Another constraint that can be applied to Message class is to make sure that the sender and receiver agents of a message are two different agents. The rules in Fig. 1 will establish a commitment object between communicating agents, and the violation rule is used to enforce the constraint where the sender and receiver should not be the same.

SPIN operates on closed-world reasoning assumption; therefore, rules update to superclass will be inherited by the subclasses as well. The temporal proposition class which requires closed-world reasoning is to infer the temporal proposition status of undefined, true or false over temporal value. The rules shown in Fig. 2 are used to update the temporal proposition from undefined to IsTrue or IsFalse based on the event (such as message exchange event).

The commitment class which requires closed-world reasoning is to infer the commitment status of activated, cancelled, fulfilled, pending and violated, and the rules are shown in Fig. 3.

Besides that, rule can be used to infer the action actor as the debtor of the commitment because the debtor is the agent who obliged to bring about some state of affair or action relative to the creditor agent. The rule shown in Fig. 4 is to insert the agent's committed action to bring about some state of the world after the debtor has agreed to commit to certain commitment.

```
Message:
   CONSTRUCT  {?this              :hasCommitment           ?com .
               ?com               :hasCreditor             ?creditor .
               ?com               :hasDebtor               ?debtor . }
   WHERE      {?this              a                        :Message;
                                  :hasCA                   ?ca .
               ?ca                a                        ?arg1 .
               ?this              :hasSender               ?creditor ;
                                  :hasReceiver             ?debtor . }

   CONSTRUCT {_:violation         a                      spin:ConstraintViolation ;
                                  spin:violationRoot       ?this ;
                                  spin:violationPath       :hasReceiver ;
                                  spin:violationValue      ?receiver ;
                                  spin:violationLevel      spin:Error ;
                                  rdfs:label               "sender and receiver
                                                            agent should not be the
                                                            same agent" }
   WHERE      {?this              :hasSender               ?sender .
               ?this              :hasReceiver             ?receiver .
               FILTER (?sender = ?receiver) . }
```

Fig. 1 SPIN rules and constraints attached to the Message class

```
IsTrue:
      DELETE        {?this          a                :Undefined . }
      INSERT        {?this          a                :IsTrue . }
      WHERE         {?this          :hasStart        ?tStart ;
                                    :hasEnd          ?tEnd .
                    FILTER (?arg1 > ?tStart and ?arg1 < ?tEnd) }
IsFalse:
      DELETE        {?this          a                :Undefined .
                    ?this           a                :IsTrue . }
      INSERT        {?this          a                :IsFalse . }
      WHERE         {?this          :hasEnd          ?tEnd .
                    FILTER (?arg1 > ?tEnd) }
TemporalProposition:
      spin:rule     {a                          spl:InferDefaultValue ;
                    spl:defaultValue            Undefined ;
                    spl:predicate               rdf:type }
```

Fig. 2 SPIN rules and constraints attached to the TemporalProposition class and its subclasses

Fig. 3 SPIN rules and constraints attached to the Commitment class and its subclasses

time	t=0	t=1	t=2
tpBuyBook	IsTrue		
c(buyer, seller, commitment)	undefined		
tpSellBook		IsTrue	
c(buyer, seller, commitment)		Activated	
tpDeliverBook			IsTrue
c(buyer, seller, commitment)			Fulfilled

```
Commitment:
    spin:rule      {a                            spl:InferDefaultValue ;
                    spl:defaultValue   Pending ;
                    spl:predicate                rdf:type   }
Activated:
    DELETE         {?this    a                              :Pending . }
    INSERT         {?this    a                              :Activated .}
    WHERE          {?msg     :hasCommitment                 ?this ;
                             :hasContent                    ?tp1;
                             :hasCondition                  ?tp2 .
                    ?tp1     a                              Undefined.
                    ?tp2     a                              IsTrue . }
Fulfilled:
    DELETE         {?this    a                              :Pending .
                     ?this   a                              :Active  }
    INSERT         {?this    a                              :Fulfill . }
    WHERE          {?msg     :hasCommitment                 ?this ;
                             :hasContent                    ?tp1;
                             :hasCondition                  ?tp2 .
                    ?tp1     a                              IsTrue .
                    ?tp2     a                              IsTrue . }
Violated:
    DELETE         {?this    a                              :Pending .
                    ?this    a                              :Active }
    INSERT         {?this    a                              :Violated . }
    WHERE          {?msg     :hasCommitment                 ?this ;
                             :hasContent                    ?tp1;
                             :hasCondition                  ?tp2 .
                    ?tp1     a                              IsFalse .
                    ?tp2     a                              IsTrue . }
```

Fig. 4 SPIN rules and constraints attached to the Action class

In the previous work, the FIPA-ACL ontology with required terms and vocabulary for FIPA-ACL communication was developed. However, the ontology does not include the required semantic model. In this work, SPIN is used to model the social semantic and enforce the social semantic through rules and constraints. SPIN is used in this work because of its ability to create rules and constraints that are linked to different OWL classes. Besides, reusable SPARQL functions can be created to automate the computing process of the queries.

A simple simulation of book buying and selling scenario implemented using JADE is used to verify the conformance of FIPA-ACL ontology and SPIN rules for

```
Action
      CONSTRUCT {   ?this     hasActor ?agent1 . }
      WHERE     {   ?tp       hasAction          ?this .
                     ?msg     hasContent         ?tp .
                    ?msg      hasCommitment      ?com
                    ?com      hasDebtor          ?agent1. }
```

Fig. 5 Verification steps for simple book buying and selling scenario

communication exchange. The verification is verified through the inspector agent to capture all the message exchanges between agents. The results showed that the FIPA-ACL ontology and SPIN rules react accordingly based on different contexts. Figure 5 shows a simple verification step.

5 Conclusion and Future Works

This paper illustrates the modelling using OWL and SPIN for FIPA-ACL ontologies which incorporates the notion of social semantic into FIPA-ACL ontologies. Using SPIN to model social semantic, it can automate the enforcement process through the constraints and rules to be applied to particular class due to the object-oriented characteristics of SPIN. Therefore, enforcing semantic constraint through rules, constraints and functions and attaching them to the class definition can prevent from any inconsistencies in the ontology. SPIN is different from SWRL in which it allows object-oriented modelling to link classes with different rules and constraints. It also allows for the creation of reusable functions that can be used in other queries which is difficult to implement in SWRL. Besides that, SPIN closed-world assumption reasoning feature does not require additional operator to reason in the open-world assumption of semantic web technologies. The next step is to test and verify the FIPA-ACL ontology together with the rules modelling in more complex scenario and verify the usability of the model. It is possible that FIPA-ACL ontology can then be further extended to incorporate different interaction protocol models. Besides that, these rules can be further enhanced with an evolved version of SPIN (SHACL) to incorporate newer features provided by SHACL.

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An Agent-Oriented Group Decision Architecture

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Abstract Group decisions are useful and crucial across socio-technical contexts, but there is a lack of generic, systematic, and comprehensive architecture that can support decision-making practically. In this paper, we propose an agent-oriented group decision architecture. It provides separate but unified representation formalisms for both global interaction protocols and local decision rules. An accompanied runtime coordination mechanism is offered, as well as an engine for agent interpretation of global and local levels of interactions towards decision-making. The architecture is general enough for group decision-making across disciplines.

Keywords Agent · Group decision-making · Protocol · Rule

1 Introduction

Group decision-making has become increasingly important. Its applications ranging from everyday organizational decisions to retailers' sourcing decisions for products provided by alternative vendors or pricing decisions for products selling to potential customers [1, 2], as well as life-critical clinical decisions for patients among a group of specialists [3, 4]. In making a group decision, multiple parties with complementary data, knowledge, capabilities, experience, and preferences are brought together, to solve a complex problem or reach a joint decision that is beyond each individual's power. Due to the increased availability of data and knowledge but decreased time to spend on the investigation, the heightened requirements of accuracy and efficiency but shortened deadlines, the augmented frequency of decisions but limited resources, providing decision support and improving decision quality is vital. Traditionally, group decisions involve social interactions and require everyone to be at the same place and at the same time in the real world. This becomes increasingly unsuitable and inconvenient in modern time due to the nature of distributed sites

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of expertise, distributed resources available to decision-making, and more and more regular decision demands. Even worse, good local decisions together sometimes turn out to be not good enough globally, and coordination among a group can be difficult. It would be much desirable, in various socio-technical contexts, to coordinate geographically spanned decision makers wherever they are, whenever decision needs emerge, and yield the most optimum decision outcomes possible. Better still, they are grouped opportunistically, and decision support is provided in a user-friendly manner. These raise some considerable challenges.

For these reasons, we believe a well-defined software architecture shall be in place to support group decision-making systematically. Here, we are interested in the design of an architecture characterized by supporting *fully distributed and open*, *highly interactive and heterogeneous*, and *semi-intelligent* group decisions. First, geographically distributed decision makers can, at their own wills, be joined together in such an architecture. Wherever necessary, they can be put flexibly into different groups to solve different decision problems. Second, the fact that the decision support architecture runs across multiple sites shall be transparent to human decision makers. Their decision processes can be guided by local interactive interfaces, in a stepwise manner. This is via integration of decision support into their routine working environment, no matter it is a desktop, a web, or a mobile application. Third and finally, as the decision processes unfold, data and knowledge currently relevant to a decision can be available to the decision makers as well as required from them. Decision options can be ranked, and prompted for their consideration at the very point that a decision is to be made. The underlying architecture shall by no means commit decisions in a fully automatic or intelligent manner without human intervention, as decision outcomes often have social impact. Therefore, the aimed group decision architecture shall address three prominent issues:

(1) The **organization of individual decision makers** across geographically distributed sites, **and their dynamic coordination** at group decision runtime.
(2) The **provision of interactive interfaces to decision makers** as automatic as possible.
(3) The **collection and presentation of data and knowledge relevant to each decision**, leading to decision option ranking and user commitment.

We propose an agent-oriented architecture in order to address the above issues. *Agents* are computational entities with general features of autonomy, concurrency, decentralization, proactiveness, social-ability and flexibility [5]. They are also endowed with human-like mental and cognitive characteristics such as belief, goal, plan, commitment, and so on. Among the Agent-Oriented Software Engineering (AOSE) methodologies, BDI [6] is useful for modeling beliefs and goals, Gaia [7] and FIPA AUML modeling agent roles and interactions, Tropos [8] and *i** [9] modeling goals, plans, dependencies, and establishing interdependency among agent actors, and KAOS [10] decomposing goals into responsibilities, capabilities, or constraints for direct assignment to agents. In fact, the autonomy and decentralization features make agents very suitable for distributed computing. The mental and cognitive characteristics make them very suitable for decision-making. The social-ability