Business Intelligence Fusion Based on Multi-agent and Complex Network

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***Abstract*—A fusion method of heterogeneous business intelligence (BI) technologies is put forward, named agent-network. This method treats BI system as a complex network composed of agents as its nodes. One agent is a unit of intelligence resource (IR) representing a computing model or an algorithm. A BI technology is a group of agents. Three basic mechanisms are discussed in detail. The IR aggregating and optimizing mechanisms can improve BI software to be a dynamical and flexible system. New technologies can be added into BI software continuously and less value existing technologies can be deleted from it. The IR using mechanism can always let the BI system to select an or a group of optimal technology (technologies) to respond to every specific user request by using some marketing mechanism such as negotiation, bidding and auction. The IR optimizing mechanism can keep the best agent and delete inferior agent by the performance of agents. The BI architecture is proposed based on our method. Different enterprises can customize their own BI service at a lower cost by using our method. In the future, we will develop a prototype software system based on our agent-network method to improve the decision level of enterprise.**

***Index Terms*—business intelligence, agent-network, multi-agent, complex network**

I. Introduction

At present, more and more enterprises need BI software to support their statistics, analysis, forecast and decision-making. Some big companies, such as Oracle, SAS, BO, Cognos, MS, SAS and SPSS, have developed their own BI software. But those BI softwares are developed for some special application and only used in a limited range. Currently, the existing BI software is deficient in three points. Firstly, the current BI software can only provide solution for specified situation. If the situation is beyond its range, it can't recognize it and respond to it. Secondly, the current BI software can't deal with the dynamical requirement of enterprise. If the requirement is changed with time, the responding capability of the BI software is weakened. Lastly, the update speed of current BI software is slow. The source code of BI software must be always rewritten when new requirement is added. So the updating cost is high. In the current market, there is a need for an universal BI software that can meet the dynamical and various requirement of heterogeneous enterprise and can fuse all kinds of heterogeneous intelligence technologies together on one BI software.

In order to develop such a BI software, we propose an fusion method for intelligence resource named agent-network based on multi-agent and complex network. This method treats BI as a complex network composed of agents as its nodes. One agent is a unit of intelligence resource which represents computing model or algorithm. Each BI technology is composed of a group of agents. The massive accumulation ability of complex network can help aggregating all the useful and new agents continuously into the system to make the system update more seamlessly and inexpensively. The optimal reorganization feature of multi-agent can help selecting the best agents to deal with the dynamical requirement of user's service at any time. Therefore, not only all the useful intelligence resource (IR) can be aggregated in the BI system, but also the optimal agents which represent the most suitable BI technology can be selected to respond to the service request of user at any time. With our method, the BI software can be updated without modifying the source code, only adjusting the construction of agent-network by adding or deleting some agents. So our agent-network method is meaningful for providing a new solution to deal with the adaptability and compatibility of BI.

The rest of the paper is organized as follows. Section 2 discusses related research. Section 3 discusses our proposed fusion method of BI and the three mechanisms of agent-network for BI fusion. Section 4 discusses the fusion levels of our proposed method. Section 5 analyzes the feasibility of our method. Section 6 summarizes our research work and discusses directions for future work.

II. Related Work

A. Multi-agent Oriented BI System

Multi-agent systems as a standard communication

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platform can interchange data and tasks [1]. The multi-agent systems have characteristics such as autonomy, reasoning, reactivity, social abilities, pro-activity, usability and adaptability [2-3].

Recently, multi-agent technology is used more and more in BI system for modeling and studying. Using multi-agent technology can make the BI system more adaptable, renewable, flexible, and extensible. The goal of intelligence fusion can be realized by multi-agent. I. Perko et al. [4] proposed a solution for multiple prediction models management and a uniform result representation by using multi-agent system and knowledge reasoning. The proposed system is adaptive, allowing the modifications and upgrading more easily and inexpensively. J. Bajo et al. [5] proposed a multi-agent system aimed at providing advanced capacities for risk management in small and medium enterprises. The agents in their system are characterized by their capacities for learning and adaptation in dynamic environments. F. Borrajo et al. [6] introduced a new business simulator named SIMBA based on web-based platform for business education and business intelligence. In SIMBA, the simulated market can be more complicated by using intelligent agents that is to assume the role of competitors. The proposed system has several key advantages in learning objectives, the development of work skills and the teaching function. K.I.K.Wang et al [7] proposed a novel ambient intelligence platform to facilitate fast integration of different control algorithms, device networks and user interfaces. The intelligence platform consists of four layers, including ubiquitous environment, middleware, multi-agent system and application layer. The multi-agent system can incorporate multiple control algorithms as agents for managing different tasks. For this, the offline control errors can be reduced greatly in comparison with single process control algorithms. The system seems to be more flexible development and future improvement. M. Janssen [8] developed a semi-cooperative architecture based on multi-agent in which human-beings or other agents can substitute agents without affecting other parts. The initial system can start with a few agents having relatively simple behavior and then be extended into a more comprehensive system. And some researches use multi-agent and other technologies to make the BI system more efficient, intelligent and automatically. A.L.Symeonidis et al. [9] proposed a method that can dynamically extract knowledge to improve agent intelligence by using data-mining and multi-agent technology together. The concept of training and retraining are described in detail. By this way, the system can be more efficient and intelligent. H.Pham [10] proposed an agent-based hypothetic agent-based model for carrying out business automation in large, distributed, and real-time business system. In their model, the agent-based components of a business organization can be created and integrated automatically into the system. They focused on controlling the agent interactions to achieve system reliability and regulate the agent visibility. Zhisong Hou et al.[11] designed a distributed intrusion detection system based on mobile agent. The dynamic adaption of the system could be implemented while false alarm rate and false negative rate would be reduced. Weidong Zhao et al.[12] designed a multi-agent middleware for mobile supply chain management, aiming to solve integration problems and achieve mobile supply chain dynamic integration. Walaa H.E. et al.[13] studied a cooperative search of autonomous agents that represent agents' coalition formation to enjoy a price discount for each of its requested service to achieve a goal. Besides the above research, multi-agent technology is used widely in dealing with all kinds of business tasks, such as trades[14], negotiation[15], bidding[16], auctions[17], supply chain[18] and warehouse management[19] for decision-making and data analysis. It seems that it's feasible to use multi-agent technology in BI system. But currently, all the existing researches are put forward to dealing with specified business tasks for one or such a kind of enterprise. And there is no such an BI software that can meet the requirement of all kinds of heterogeneous enterprises. So in this paper, we propose a method that tries to solve this problem.

B. Multi-agent and Complex Network

Multi-agent system is a distributed system based on network [20]. And especially, the internet as an important environment of multi-agent is a typical complex network[21]. The relationship between agents is a kind of complex network. [22-24] studied the statistic feature of entity in large distributed system by graphical analysis method. The result showed that the relationship of agents which denotes the entity has features of complex network, such as small-world and scale-free. J.Delgado[21] also pointed out that the topology of agents treated as complex network is more suitable than ruled-network. And at present, some existing researches develop some models and software based on multi-agent and complex network. N.Celik [25] developed an optimal workforce assignment module based on multi-agent to resolve the problem of short-term and long term tasks of alliance-based multiple organizations which forms a complex social network. The behavior of the complex social network can be predicted by using agent-based simulation. Each agent represented an individual in the organization network and had its own characteristic. M.Tran[26] developed an agent-based model to investigating the role of individual behavior and studying the complex network influence on energy innovation diffusion. M.B.Hu [27] studied the wealth distribution in different social networks. In their proposed model, they used agents to play as nodes of the complex social network and studied the agents' personal wealth to find the law of wealth distribution. All the above researches show that the agents can be treated as nodes of complex network. The agent as node has its independent functions and interacts with each other. From the complex network perspective, the relationship of agents can be described more clearly.

III. AGENT-NETWORK METHOD FOR BI

On the basis of existing researches, a new intelligence fusion method named agent-network based on multi-agent

and complex network is proposed. In this method, all kinds of useful BI resources are formed to be a series of agents which are aggregated organically as nodes of complex network. The complex network acts as a container of agents. Then the optimal agents are selected according to their performance. The intelligence fusion mechanism of agent-network is in figure 1. There are three fusion mechanisms, including IR optimizing mechanism, IR using mechanism and IR aggregating mechanism. In the following, we will discuss the three mechanisms in detail.

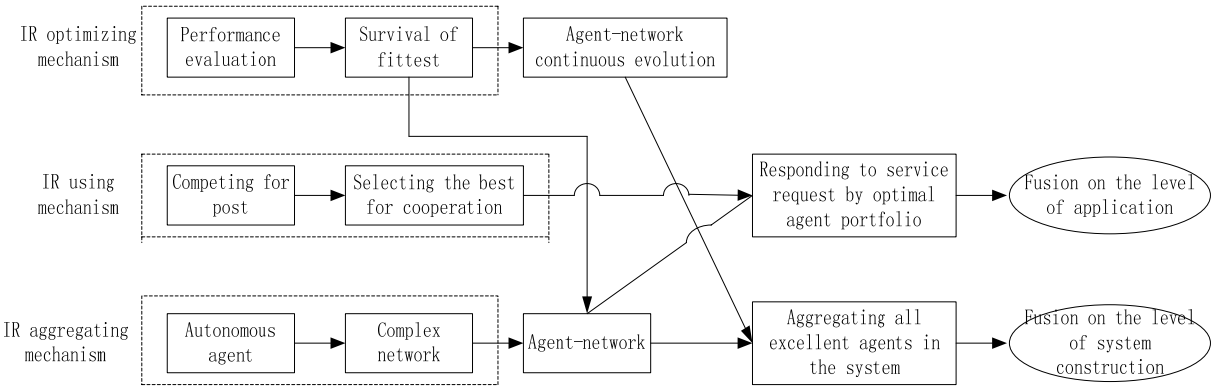


Figure 1. Intelligence fusion of agent-network

A. IR Aggregating Mechanism Based on Autonomous Agent and Complex Network

An agent is one unit of packaged IR. The agents represent the corresponding IR. The representation of agents brings great convenience for reorganization and reuse of IR. There are various BI technologies from different fields, such as artificial intelligence, mathematics and so on. Each technology has a series of computing models or algorithms for constructing IR. Computing model is the basic unit of IR. Each model has a certain computing ability which can complete one or several complex computing tasks. Therefore, each computing model can be packaged into an agent.

The agents can be classified into three levels: atomic agent (AA), natural agent (NA) and group agent (GA). Their relationship is in figure 2. A NA denotes a natural computing model or algorithm. A BI technology is composed of a series of mutually cooperative NA which construct a GA in agent-network. In order to reorganize and reuse agents, a natural agent can be split into some atomic agents which are the indivisible agent unit. In figure 2, we can see there are two modes of GA construction. One is that the NAs similar to each other can construct a GA. For example, some NAs representing algorithms or models based on genetic algorithm can construct a GA of genetic algorithm. In this GA, a basic genetic algorithm is the base of other modified genetic algorithms. And other NAs can cooperate with this GA, not only one agent of this GA. Another is that some cooperative NAs from different field can also work together to construct a GA for responding to the same user's service.

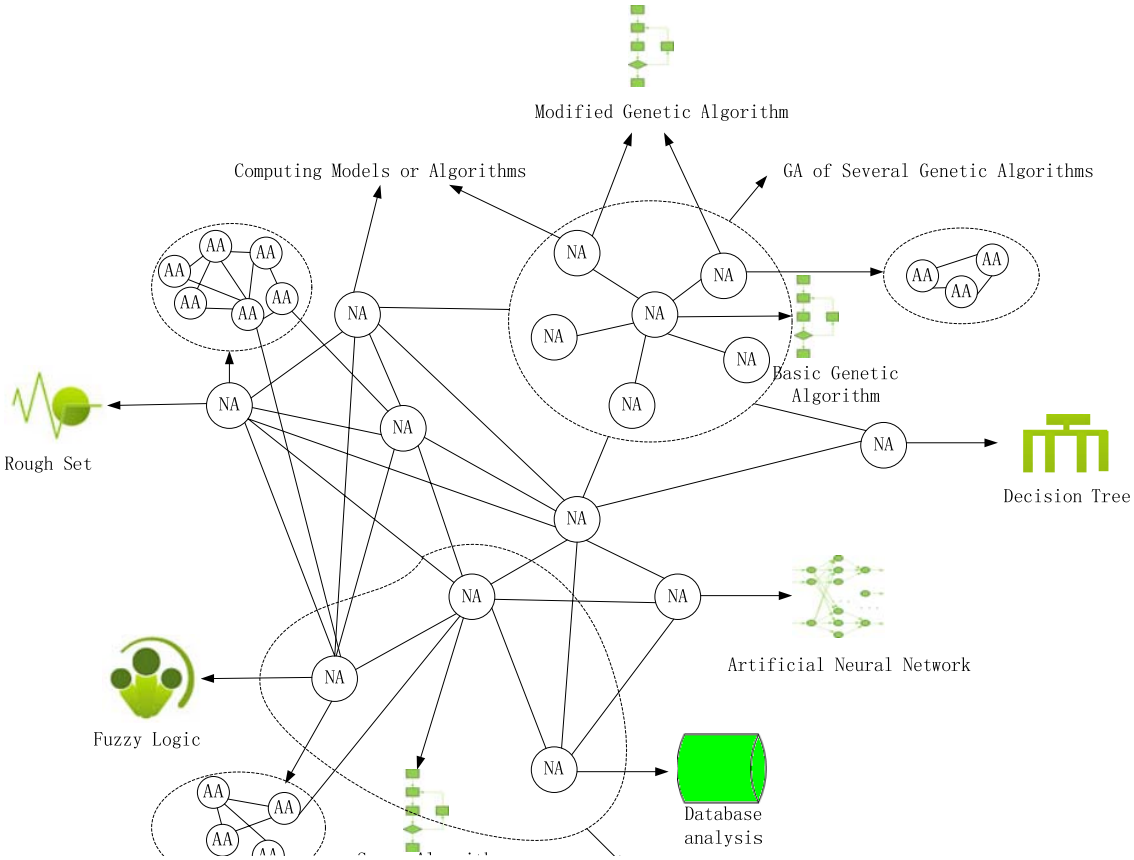
IR aggregating mechanism based on complex network is to aggregate the agents in the complex network. Therefore, each agent is treated as one node of the complex network. The cooperation between agents can be judged by the edge of complex network. As in figure 3, the weighted edge denotes the degree of close relationship between agents. So, a complex network of weighted agent is formed. For interactive relevance and infinite expandability of complex network, not only the existing BI resource can be aggregated, but also the new resource can be added in the system at any time. The agent at one node can be NA or AA, but not GA which is an agent sub-working net in actually. In figure 3, the initial edge weight is supposed to be 1. With the development of this agent-network after completing several tasks, the edge weight is changeable. If the edge weight is far more than 1, it denotes that the agent is active and valuable. If the edge weight is minus, it denotes that the agent is bad and can't cooperate with other agents. If the edge weight is equal to 1, it seems that the agent has no cooperative experience record with other agent. The edge weight can be between NA and AA or NA or GA.

B. IR Using Mechanism Based on "Competing for Post" and "Select the Best for Cooperation"

"Competing for post" is a service mechanism for user's dynamic requirement. A group of agents are selected by competing against other groups for the post of one service request. And one agent is a special case. How to select a group of agents to cooperate with others becomes a result of competition. The agents are not pre-designated by the system. In traditional multi-agent system, the cooperative agents are selected by the system through auto-matching or pre-designation. The cooperative relationship is rigid and lack of competition. "Competing for post" mechanism breaks up the rigid cooperation. The selection of competitive agents is the key point to realize this mechanism. So, besides remaining the two traditional modes, typically competitive mechanism in realistic society, such as negotiation, bidding and auction, are introduced into the system. The auto-matching or pre-designation can be treated as special "competing for post" mechanism when there is no other method can be chosen for agents selection or the edge weight of agents reaches a high point.

"Selecting the best for cooperation" is to select a group of optimal agents to respond to current user's service

request by using "Competing for post"mechanism. Face to each service request of user, the system can flexibly choose one or several cooperative mechanisms according to current service property, service scale and status of respondent agent resource. Then, the optimal cooperation agents can be selected according to the rules of selecting the best for cooperation" mechanism. Of course, the rules and process of each mechanism are different for different situation in different complex degree. Therefore, the system must design a set of rules to guide the optimal agents' selection at the current situation when responding to each user's request. As in figure 4, we can use decision tree to build up the optimal selection rules to choose the optimal group of agents in different situation. The rule database can be divided into enterprise type, service type, service requirement and corresponding groups of optimal agents. Face to a service requirement, if the service requirement is not new, we can search for the group of optimal agents in the decision tree. If the service requirement is new, we can add it to our decision tree for next service selection.



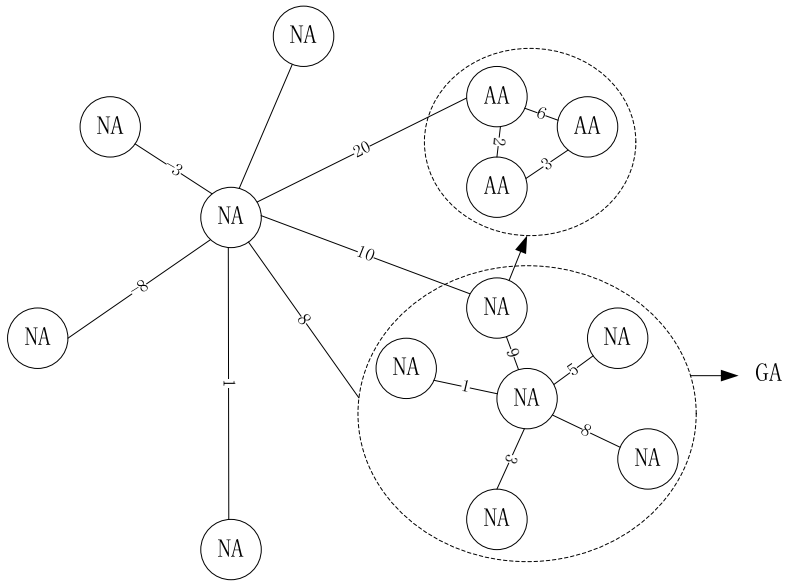


Figure 3.Weighted edge of agents

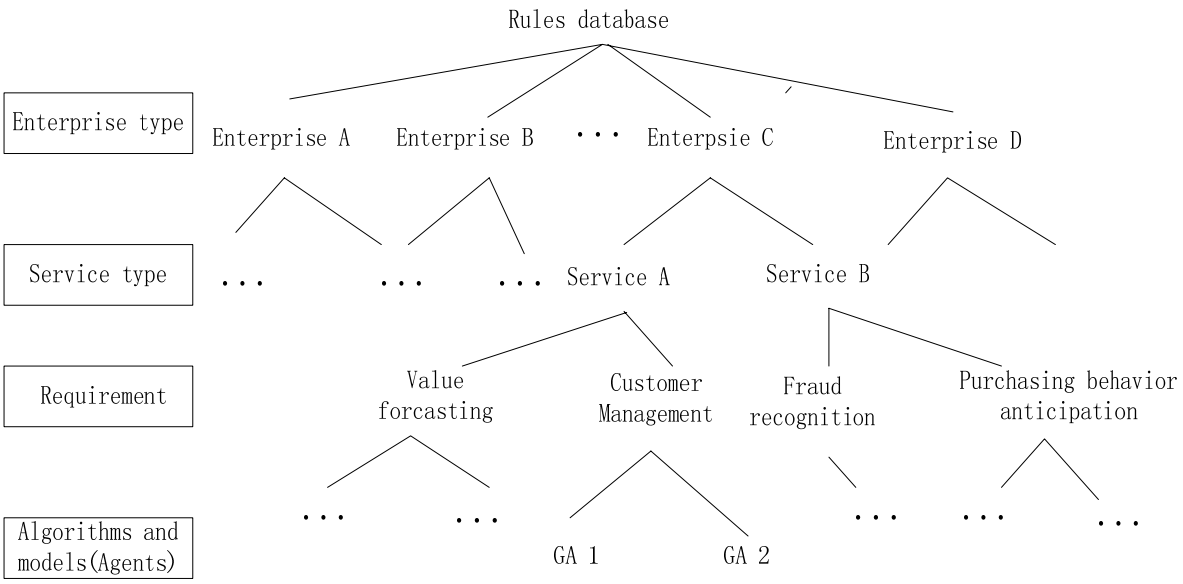


Figure 4.Decision tree for optimal group agents' selection

C. IR Optimizing Mechanism Based on Performance Evaluation and the Rule of "Survival of the Fittest"

In the agent-network, the distributed agents as nodes of complex network have independent functions and can be interactive with each other. The cooperative agents can provide intelligence services, including profitable customer relationship management, market forecasting, deal deception identification, users' monetary contribution perception and so on. Each service is a respondent for users' requirement. Performance evaluation is a mechanism to measure the service performance of agents, including real-time evaluation and periodic evaluation. Real-time evaluation is to evaluate the performance of all the agents participating in the current cooperation after the service completion. The evaluation result is the basis for updating edge weight which reflects the cooperative relationship between agents. The edge weight is bigger when the number of successful cooperation is more and the performance result is better. The cooperation opportunity is determined by edge weight which is an important judgment for periodic evaluation. Periodic evaluation is to evaluate the performance of all the agents in a long time. The change of edge weight is very important for periodic evaluation. As in figure 3, if the edge weight of one agent is not changed after a period of working time, it seems that there is no cooperation record between the agent and other agents. So the edge weight is equal to the initial edge weight which is always 1 in our proposed agent-network. It shows that the agent has no chance in cooperation with other agents. The agent is called inert agent which is similar to the worthless goods in the warehouse of enterprise. If the edge weight of one agent is minus, it shows that the agent has several times of failing cooperative experience. The agent is called inferior agent which is similar to inferior-quality goods. If the edge weight of one agent is far bigger than the initial edge weight, it shows that the agent has several times of successfully cooperation experience. The agent denotes the superior IR. The basic task of periodic evaluation is to identify inert agents and inferior agents.

"Survival of the fittest" is a mechanism like the juggle-law of nature. The inert agents and inferior agents can be eliminated from agent-network according to a certain rules. And the excellent agents can be remained in the agent-network. So the aggregated IRs in agent-network has the continuous evolution characteristic which is like ecological features of juggle-law.

IV. AGENT-NETWORK FUSION LEVEL

As shown in figure 1, IRs can be fused organically on the level of system structure and system application by use of three agent-network mechanisms.

A. Intelligence Fusion on the Level of System Structure

Intelligence fusion on system structure means that all kinds of superior BI resource persistently can be aggregated in BI system. IR aggregating mechanism based on autonomous agent and complex network ensures that the existing and new IRs can enter in system in form of conveniently used agent and form a dynamical agent-network whose capacity is infinite. IR using mechanism based on "competing for post" and "selecting the best for cooperation" ensures eliminating inferior IRs and remaining superior IRs. Therefore, the fusion on the level of system structure ensures that the system is the best at any time. The fusion on the level of system structure is the base of intelligence fusion on the level of system application.

B. Intelligence Fusion on the Level of System Application

Intelligence fusion on the level of system application means that the system can select the most appropriate BI resource to provide best service for users in a flexible and variable way. The fundamental purpose of intelligence

fusion is to respond to user's service request better. If there is no intelligence fusion on the level of system application, the fusion on the level of system structure is meaningless. IR using mechanism based on "competing for post" and "selecting the best for cooperation" ensures selecting the best agents dynamically to respond to current user's request. In this way, the fusion on the level of system application is realized. The granularity of agent (*basic cooperation unit of agent*) in system application can be classified into three levels: GA, NA and AA. The cooperative agent portfolio is more plentiful with smaller granularity of agents. And the adaptability of agents is more widely. The three levels of agent granularity can be used cooperatively at the same time when responding to user's service request.

V. FEASIBILITY ANALYSIS

In order to realize above fusion mechanisms, we must have two key technologies, including agent representation of heterogeneous BI resource and software technology of "selecting the best for cooperation". In the following, the feasibility of the two technologies is discussed in detail.

A. Feasibility of Agent Representation

Agent representation of BI resource is to package BI resource into a series of agents which have their characteristic. Each agent denotes a computing unit. Each BI technology becomes a group of agents after representation. Agent representation is the base of realizing intelligence fusion. There are two meanings: firstly, multidisciplinary BI resource agent can be homogenous after representation. The agent is similar to component which can be reused and used repeatedly. Secondly, the characteristic of agent, including subjectivity, intelligence, adaptability and society [28](Shi C.Y. et al.,2007), provides necessary premise for agent to take part in competition like individual and enterprise in realistic society.

Can the multidisciplinary BI resource be represented in the form of agent? The answer is yes. Many researchers propose various BI methods based on agent. For example, genetic algorithm based on multi-agent[29], production orders resolution by employing an expert system and a neural network based on multi-agent[30], a fuzzy logic controller based on multi-agent[31], data-mining for extract knowledge based on multi-agent[12]. The existing researches show that the combination of BI and agent becomes a research trend and its realization is feasible.

B. Feasibility of Competition Mechanism

Competition mechanism, such as negotiation, bidding and auction, is the key point for realizing "competing for post" and "selecting the best for cooperation". The existing researches show that the Competition mechanism can be used to effectively allocate task and resource in multi-agent system[28]. For example, some researchers proposed several agent negotiation methods based on reasoning-case, consultation theory, confliction theory and sort facility[32]. A multi-agent system based on auction negotiation is used to resolve distributed multi-project scheduling[17]. A software architecture called"market-like" becomes one of the three typical architecture of multi-agent system [28]. In this architecture, negotiation, bidding and auction are realized all. And currently, in e-commence or e-market, multi-agent technologies are also used in dealing with negotiation [15] and bidding [16] to improve the efficiency of system. All the above researches show that it's feasible in technology to build up competitive cooperation of agents by introducing negotiation, bidding and auction.

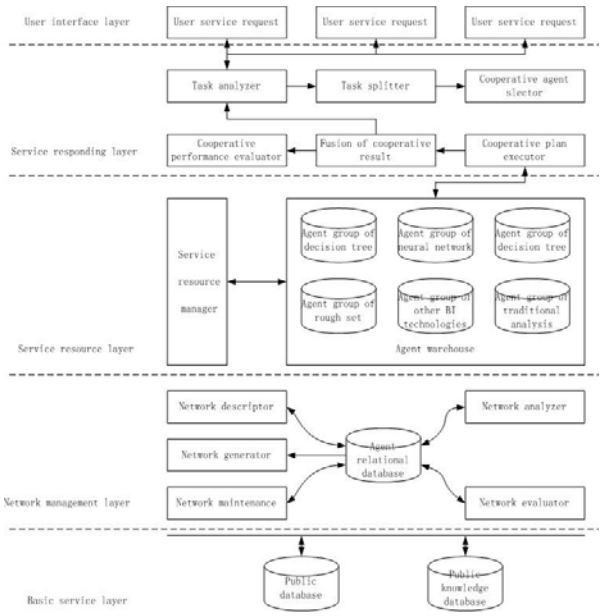


Figure 5. Software architecture of BI system based on agent-network

VI. Architecture Of BI System Based On This Method

In this paper, we propose an architecture of BI system composed of user interface layer, service responding layer, service resource layer, network management layer and basic service layer, as figure 5 showing. Several technologies can be fused by use of this architecture.

A. User Interface Layer

There are two functions in user interface layer: request acceptation and service result return. Request acceptation provides registration, reservation and logout for users. At the same time, the service task is generated and then sent to service responding layer. Service result return provides return result display and satisfaction enquiry for users. Then the information of satisfaction is sent to service responding layer for evaluating performance of current agent combination.

B. Service Responding Layer

Each responding of user's request is a new cooperation of a group of agents in agent-network. The dispatching mechanism is to determine which agent can participate in cooperation with others according to the dynamical property of task. The service responding layer is an intelligent dispatching mechanism and a control center. All kinds of BI services are fused on system application after task completion in service responding layer. The service responding layer is composed of task analyzer, task splitter, cooperative agent selector, cooperative plan executor, fusion of cooperative result and cooperative performance evaluator. Task analyzer is to recognize the structured degree, complex degree, work load and decomposability and provide basis for selecting task decomposing strategy and task responding strategy. Task splitter is composed of task decomposing strategy set, suitable strategy condition set and selective strategy rules set. The task decomposing plan is determined by task splitter according to the suitable decomposing strategy and the decomposing granularity. Cooperative agent selector is composed of cooperative strategy set, suitable condition set, selective strategy rules set, operating process and algorithms. The optimal cooperation that can realize fusion of all kinds of BI on system application is ensured by selecting the most suitable cooperative strategy of current task and completing the final agent selection according to the corresponding process and algorithms. Cooperative plan executor is to send command to the selected agents and receive task execution result according to cooperative plan. At the same time, it's responsible for communicating and coordinating between agents. Fusion of cooperative result is to gain the final result by dealing with the return result of cooperative agents. For complex cooperative task, especially non-constructive computing task belonging to soft computing, some information fusion technologies, such as Bayesian inferences, D-S evidence theory, fuzzy set theory, expert system, artificial neural network, are used to deal with the cooperative result comprehensively. Cooperative performance evaluator is to organize related subjects users and related agent to evaluate the performance of cooperative agents, store performance result in public database, trigger network management layer to update the edge weight, and inform service resource layer to record the cooperative performance.

C. Service Resource Layer

Service resource layer is composed of agent warehouse and service resource manager. The agent warehouse is the physical place for computing resource fusion on system construction in the form of agent. Each computing resource of BI technology is packaged into a series of subjectivation agent. The agents of the same method constitute a group of close relationship agents. These agents are the entity of executing service task and the base of BI system. Each agent can be participate in cooperation as an individual or part of a agent group. The agent warehouse is dynamic open, not only including various existing BI technologies, such as rough set, fuzzy logic, decision tree, group decision, swarm algorithm, data mining, genetic algorithm, artificial neural network and other traditional statistics and analytical technologies, but also adding the new technologies into the agent warehouse at any time.

The service managers is to load, upload, import, export, and maintain agents' record which is including list maintenance, warehousing registration, cooperation registration and performance records. The service manager is also to assist network management layer to maintain agent list in the warehouse consistenting with node list of network. The agent list in the warehouse must contain node list of network, otherwise the no-existing agent would be assigned to respond to service request.

D. Network Management Layer

The network management layer is composed of network describer, network generator, network maintenance device, performance evaluator and network analyzer. Network describer provides an effective operation and management tool for users to construct the initial agent cooperative network. Users can easily describe the network composed of agents as nodes and their mutual relations, including node list of network, relational path and strength between nodes. Furthermore, the network relationship attribute database is formed for editing, adding, deleting, modifying and storing of complete network information. Network generator is to generate agent cooperative network according to data of relationship attribute. The generated network is a weighted cooperation network which has cluster structure. The weight reflects the relationship between agents. Cluster is a group of close relationship agents which denote one BI technology. Network maintenance device is to add new nodes, new edges and assign weight to new edge according to addition commands and algorithms. Network maintenance device is to delete the corresponding nodes according to deletion command and algorithms, update edge weight according to weight updating command and algorithms. Performance evaluator is to evaluate all the agents of the whole network in a long period, recognize dull agent and inferior agent

according to a certain rules, inform network maintenance device to delete dull agent and inferior agent from network and inform service resource manager to clear away the dull agent and inferior agent. Network analyzer is to calculate and analyze the network statistical characteristics, such as all nodes, all edges, average degree, average path length and cluster coefficient.

E. Basic Service Layer

Basic service layer is composed of public database and public knowledge base. The data and knowledge of other layers can be stored and managed in this layer.

All kinds of saving data and information is stored in public database, including history information of network construction data of cooperative agent, history information of network evolution and performance result of cooperative agents. All kinds of knowledge which is needed by network generation and task response is stored in public knowledge base, including node evolution rules, weight evolution rules, selective rules of task decomposition strategy, selective rules of task cooperative strategy, selective rules of cooperative objects and selective rules of cooperative result fusion method.

VII. CONCLUSIONS

In this paper, we proposed a new method named agent-network for BI resource fusion. The heterogeneous technologies can be fused and aggregated together in an effective way by using our method. The three fusion mechanisms are described in detail to explain how to add new and best technologies in the agent-network to meet the dynamical requirement of enterprise service. They are IR aggregating mechanism, IR using mechanism and IR optimizing mechanism. In this way, the intelligence of BI system can be evolution and suitable for the development of enterprise. The software system architecture based on our agent-network method is discussed. The agent entering in the network can be combined optimally to respond to users' service request. The excellent agents tested in practical can be remained in the network. So the current system reflects the highest level of group intelligence. The intelligence of system is constantly evolved for the endless creativity of group.

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