

A Goal-oriented Approach to Agent Identification and Coordination

Zhiqi Shen¹, Chunyan Miao² and Robert Gay¹

¹School of EEE, Nanyang Technological University

²School of Computer Engineering, Nanyang Technological University

50 Nanyang Avenue, Singapore 639798

65-67904467, 65-67906197, 65-67905405

{zqshen, ascymiao, eklgay}@ntu.edu.sg

ABSTRACT

Agent identification, organization and coordination in a multi-agent system (MAS) are important topics in agent research. Most of the existing research work try to address the above three issues separately. In this paper, a goal-oriented approach for coherent agent identification, organization and coordination based on Goal Net is presented. With Goal Net, different agents can be identified and a multi-agent system can be formed through Goal Net split. Goal Net also provides a nature solution on how agents can be coordinated. Examples from the real system development using the proposed approach are given to illustrate that the agent identification, organization and coordination are addressed in an integrated process in engineering multi-agent systems.

Categories and Subject Descriptors

I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence
– *Intelligent agents, Multiagent systems.*

General Terms

Algorithms, Design.

Keywords

Multi-agent system, Agent identification, Agent organization, Agent coordination.

1. INTRODUCTION

Agent identification, organization and coordination in a multi-agent system (MAS) are important topics in agent research. There are currently many research papers reporting various solutions to tackle these issues [5, 8, 13, 14, 15]. However, most of the current research efforts regard these issues as separate issues. As a result, these issues are tackled through separate methods and approaches. In this paper, we argue that agent identification, organization and coordination are coherent processes in engineering a multi-agent system. A novel goal oriented approach to dealing with the above

issues together in an integrated approach is presented.

The proposed approach is based on a goal-oriented agent model, Goal Net [10], which was previously proposed for goal-oriented agent modeling. Goal Net enables an agent to select the next goal to achieve and select the next action to pursue the selected goal in a dynamic environment [10]. A goal-oriented (GO) agent development methodology, namely GO methodology, based on Goal Net was also proposed in [11]. Given a problem, the *overall goal* to solve the problem could be decomposed into sub-goals. Sub-goals could be further decomposed until the hierarchical structure and the relationships of the goals are clearly defined. The temporal relationships and the transitions between the goals can be further identified. As a result, a goal net can be constructed that serves as the brain of an agent.

For a complex real problem, usually the goal net might be too complex for a single agent. A multi-agent system, in which each agent carries a sub goal net, can be formed to solve the real problem. The objective of this paper is to propose a method by which a multi-agent system can be formed from a goal net. The proposed method demonstrates an integrated solution for agent identification, organization and coordination in engineering a multi-agent system.

The paper is organized as following: Following this introduction, in the next section, the related research work is reviewed. Section 3 describes the Goal Net. In the section 4 and section 5, agent identification, organization and coordination are addressed respectively. Section 6 evaluates the proposed method and discusses its applications. The conclusion is reached in section 7.

2. RELATED WORK

The dominant direction for multi-agent system (MAS) organization is to model a MAS based on organizational theory [5, 13]. Researchers believe a MAS can be considered as organizations composed of autonomous agents that interact and cooperate with each other in order to achieve a common goal and their private goals. There are at least two ways to model a MAS: (1) A MAS is modeled according to a social organization structure so that agents are identified and organized based on the roles in the organization. The coordination among the agents is also formed according to the rules of the organization. (2) A MAS is modeled according to roles the agents play, by which an organization will be formed. The coordination among the agents will be modeled using another method, such as strategic alliance in [5].

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee.

The Fifth International Joint Conference on Autonomous Agents and Multiagent systems, May 8–12, 2006, Hakodate, Japan.

Copyright 2005 ACM 1-58113-000-0/00/0004...\$5.00.

In the first approach, although agent organization and coordination are easily modeled based on real organization structure and rules, the applications are limited because many applications are difficult to be mapped to a real organization. In the second approach, different methods need to be used for agent organization and coordination respectively. Furthermore, it is not clear how to identify roles (agents).

Other than above-mentioned methods, most of existing work does not provide an integrated method to address the agent identification, organization and coordination issues at the same time. For example, [8] introduced a goal-based method to identify agents to form a multi-agent system. However, it does not address how the agents are organized and coordinated. In [14], the authors introduced a method by which the agent organization can be formed in a multi-agent system dynamically at run time. It assumes that multiple agents have been created and are running in a multi-agent system. These agents are able to dynamically form some organizations based on the proposed method. It does not address system modeling and agent identification processes in engineering multi-agent systems. In [15], a layered architecture for agent coordination was proposed. An agent organization model was also discussed in this paper. However, agent identification was missing. In summary, the existing efforts have been put in studying agent identification, organization and coordination as separate research issues.

In this paper, we argue that it is a nature way to study the above issues coherently in an integrated process for engineering multi-agent systems. An integrated approach for agent identification, organization and coordination based on Goal Net is presented. With the proposed approach, agent identification, organization and coordination in a MAS can be modeled in a coherent process using a single Goal Net model.

3. GOAL NET

An agent's goal is a desired state that the agent intends to reach. Goal Net is a composite goal hierarchy which is composed of *goals* and *transitions*. *Goals*, represented by circles, are used to represent the goals that an agent needs to go through in order to achieve its final goal. *Transitions*, represented by arc and vertical bar or rectangle, connect one goal to another specifying the relationship between goals it joins. Each transition must have at least one *input goal* and one *output goal*. Each transition is associated with a task list which defines the possible tasks that agent may need to perform in order to transit from the input goal to the output goal. Figure 1 shows a simple goal net.

There are two types of goals in a Goal Net model, *atomic goal* and *composite goal*. An *atomic goal*, represented by a blank circle, accommodates a single goal which could not be split anymore; a *composite goal*, represented by a shadowed circle, may be split into goals (either composite or atomic) connected via transitions.

In Goal Net models, there are four types of basic temporal relationships between goals: *sequence*, *concurrency*, *choice* and *synchronization*. *Sequence* relation represents a direct sequential relationship between one input goal and one output goal; *concurrency* relation has one input goal but more than one output goals, and all its output goals can achieve simultaneously; *choice* relation specifies a selective connection from one goal to other goals; *synchronization* relation specifies a synchronization point

from different input goal to a single output goal. With different combination of the basic temporal relations, Goal Net supports a wide range of complicated temporal relationships among goals. This is one of the major differences between Goal Net and other goal modeling methods.

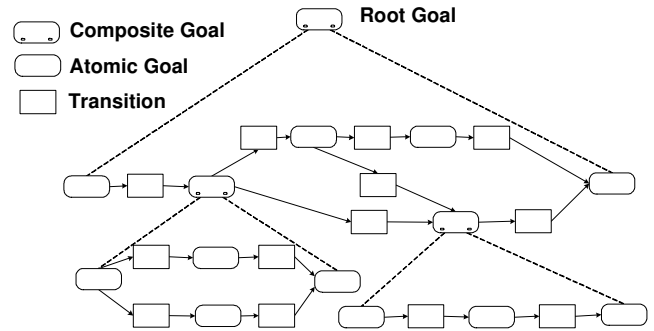


Figure 1. A simple goal net

With a composite goal hierarchy and various temporal relationships within the hierarchy, a complex system can be recursively decomposed into sub-goals and sub-goal-nets. In such a manner, the system can be easily modeled and simplified.

Goal Net supports dynamic goal selection, when one goal has a choice relation with other goals. That is, after the goal is achieved, the agent needs to decide the next goal to pursue. A goal selection function is defined in the property of this goal based on the context and considered situation of the goal in the real system.

Goal Net also supports dynamic action selection if there is more than one task defined in a transition, in which case an action selection mechanism is defined in the transition. Different action selection mechanisms can be defined in different transitions respectively in a goal net. As a result, the agent modeled using Goal Net will select the goal and task dynamically according to the real situation during run time.

To facilitate goal net based agent implementation, an agent development environment has been developed, which include an agent creator to create dummy agents (agent body), a Goal Net designer to design goal nets (agent brain), and a goal net loader to load a goal net (agent brain) into a dummy agent (agent body) [11].

4. AGENT IDENTIFICATION

4.1 Agent Identification and Organization

After an application problem is modeled with Goal Net, multiple agents can be identified from the goal model. As described, a goal net is in a hierarchical structure. Each composite goal in a goal net can be further decomposed into a number of subnets. A subnet consists of a composite goal together with its decomposition. When a goal net is too complex to be realized by a single agent, a subnet can be used to form the goal model of a new agent. As a result, multiple agents will be identified, each of which is corresponding to a subnet. Therefore a multi-agent system is derived from a goal net. Agents in a multi-agent system modeled by Goal Net, are organized in a hierarchical structure, namely *agent hierarchy*.

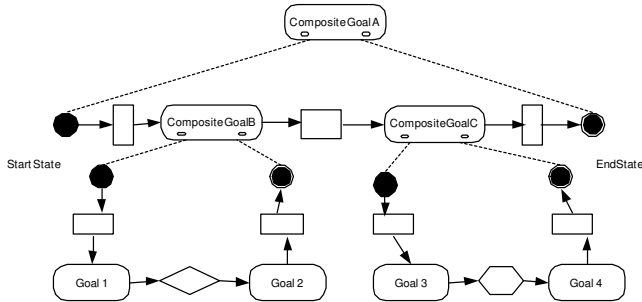


Figure 2. An example goal net

For example, a goal net shown in Figure 2 consists of three composite goals, A, B, and C, leading three subnets A, B, and C. The three subnets can be identified as goal models for the three new derived agents as shown in Figure 3. Based on the original goal net, the generated agents form an agent hierarchy.

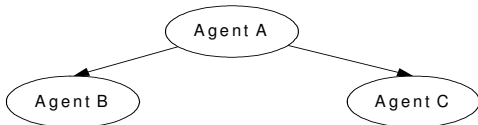


Figure 3. The derived agent hierarchy

If the composite goal is in a higher layer of the original goal net, the derived agent will also be in the higher layer of the generated agent hierarchy. If the composite goal is at the same layer with another composite goal, the two derived agents will be at the same layer in the generated agent hierarchy. The arrows indicate the hierarchical relationships between agents. As a result, in Figure 3, Agent A becomes the parent agent of agent B and C.

When a composite goal together with its decomposition in a goal net is selected to form the goal model of a new agent, the composite goal becomes the root node of the new goal net and this composite goal becomes the overall goal of the new agent. In the original goal net, the place for the split composite goal will be replaced by a *connection* goal. A *connection* goal is an atomic goal, which indicates the goal needs to be achieved through another agent. That is, it connects the goal net to another goal net. So, in Figure 2, when the subnet B and subnet C are split out, the connection goal B' and goal C' will take the places of the composite goals B and C respectively. The goal net A will then connect goal net B or goal net C through the corresponding connection goal B' or C' respectively.

The number of agents to be generated from a goal net will be decided by a split strategy. It is not necessary to select each subnet in the entire goal net to generate a new agent. Following lists some strategies for identifying agents:

- Based on similarity of the goals (for example, the goals related to data collection as a data collection agent),
- Based on roles that the identified agents will play (for example, the data collection agent, the forecasting agent in business forecasting system),
- Based on locations that the identified agents will run in (for example, the agents will run in a distributed environment in different organizations),

- Based on specific types of agents (for example, some goals will be achieved by mobile agents),
- Based on functional systems that the identified agents will belong to (for example, agents for different sub-systems),
- Based on load balancing (for example, we can balance the number of sub-goals in the identified agents to reduce the complexity and load of one agent), or
- Based on other strategies decided in a real agent application.

In following, the procedure to split a goal net for agent identification is given.

The Goal Net Split Procedure

Input: Goal Net G

Output: Goal Net set G_s

G_s ← Φ

l ← number of levels – 1;

For i = l; i > 0; i--; Loop

 For each composite goal s in level i

 If the subnet N rooted by s is split, Then

 G_s = G_s ∪ N

 Split N from G

 Create a connection goal s' to replace s in G

 Set profile of s in s'

 End If

 End For

End For

End

For a complex problem, the above strategies can be used in different levels of the goal net. For instance, at the high level, the agents are identified based on the functional systems; at the middle level, the agents are identified based on the locations; and at the low level, the agents are identified based on the roles or based on the load balancing strategy.

In the following section, an example from an e-forecasting system that we developed previously is given to illustrate how to use the method.

4.2 Agent-based e-Forecasting System

Forecasting plays an important role in the economic world. It is concerned with the processes used to predict the unknown [1]. The life cycle of e-forecasting covers processes of obtaining information, preparing forecasting method, and generating forecasts. Each of the above processes may include a set of sub-processes. For instance, the “obtaining information” process has the following sub-processes, identifying data source, collecting data, and preparing data etc. These sub-processes may contain their own sub processes. Agent-based e-forecasting system provides a software solution that can manage the processes throughout the whole life cycle of forecasting.

The system was developed using GO methodology. In the requirement analysis phase, four goals have been identified: collecting data, preparing data, training forecasting model, and generating forecast results. These four goals are sub-goals of the overall goal *providing e-forecasting services*. The four sub-goals were further decomposed and finally a preliminary goal net was constructed as shown in Figure 4.

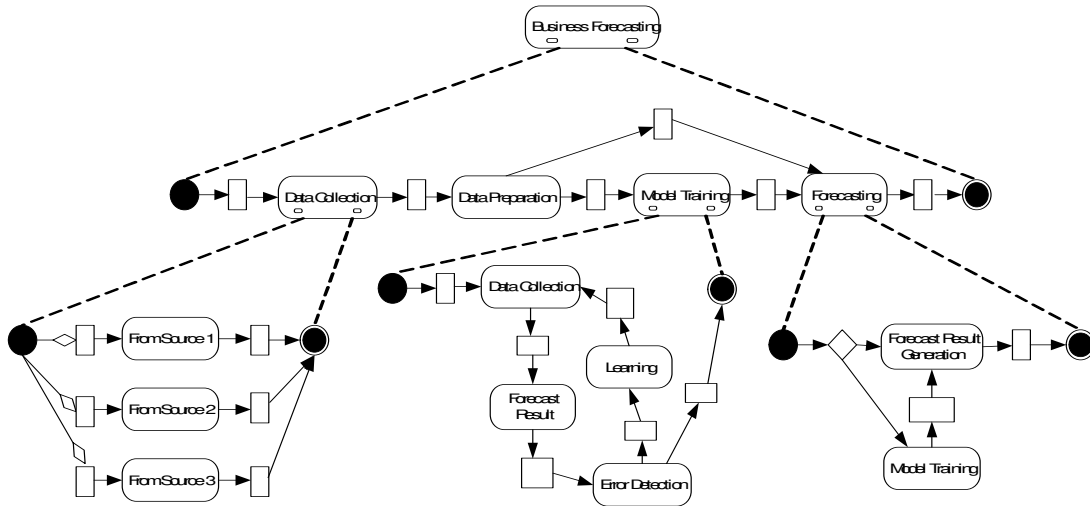


Figure 4. The preliminary goal net of e-forecasting system

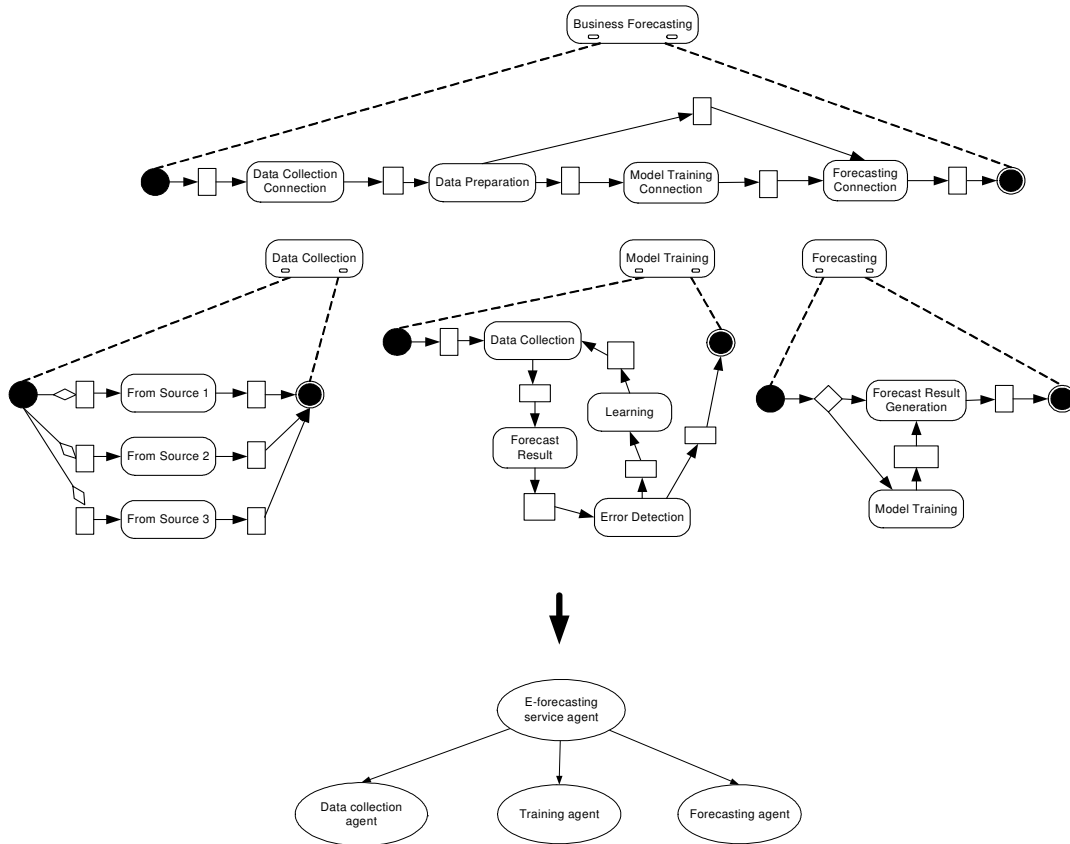


Figure 5. The goal net split and the generated agent hierarchy

In the architectural design phase, the original goal net was split to four subnets using role-based strategy. The four subnets correspond to four agents. That is, the e-forecasting service agent (formed by the original goal net without split goal nets) becomes the parent of the data collection agent (formed by the subnet for

data collection), the training agent (formed by the subnet for model training) and the forecasting agent (formed by the subnet for forecasting). The connection goals in the goal net of the parent agent become the synchronization points between e-forecasting

service agent and other agents respectively. Figure 5 shows the split goal nets and generated agent hierarchy.

In the next section, the example will be continued to illustrate that the agent coordination model will be derived using this method at the same time.

5. AGENT COORDINATION

5.1 Agent-Coordination

Agents identified by the proposed method are organized in a hierarchical structure, and forms an agent hierarchy. The higher level of agent becomes a coordinator of lower level of agents, and at the same time, it pursues its own goals. The overall goal represented in the original goal net becomes the common goal of the derived multi-agent system. The transitions between goals define the coordination tasks and schedules.

A coordinator agent assigns a sub-goal to a child agent when it is going to pursue a connection goal. The position of the connection goal in a goal net indicates the synchronization point between the coordinator and the child agent. The original goal net assures the common goal will be achieved if the derived agents achieve their own goals. In detail, when a coordinator runs to a connection goal, a sub-goal will be assigned to the child agent pointed by the connection goal. The child agent will then initialize its goal net with this assigned goal to start pursuing this goal. After the goal is reached, the child agent will notify the parent agent. The parent agent will exchange information with the child agent and then continue its goal pursuit.

For example, suppose composite goal B is a goal of the decomposition of goal A . The goal B together with its decomposition forms a goal net of a new agent B . The goal A together with the other members of its decomposition forms agent A . The agent A is then called the parent agent of agent B while the agent B is called the child agent of the agent A . The agent A has its own goals. The overall goal of agent A becomes the common goal of the multi-agent system. It needs agent B 's work to reach its own goal. It coordinates the child agents according to its goal model. The child agent starts to work when it is assigned a goal from its parent agent.

Once a goal net has been designed, it can be re-used by other goal nets. That is, a goal net can be composed with another goal net as a subnet of the other goal net. For instance, if a goal net, X , is re-used in another goal net, Y , the re-used goal net X becomes a "subnet" in goal net Y as if the goal X was split from the goal Y . The agent with the goal net X becomes a "child" agent of the agent with the goal net Y .

Once all the agents are identified, a multi-agent system is formed. The agents are created and loaded with corresponding goal nets. They run concurrently to pursue their individual goals. One goal pursuit in the multi-agent system is considered as one transaction. There could be many transactions going on in the multi-agent system at a time. So the agents may pursue their own goals concurrently for different transactions. However, the parent agents will coordinate their child agents to pursue their goals for a specific transaction. One agent can be assigned two or more goals for different transactions to improve the efficiency. For instance, when an agent assigns a sub-goal to its child agent, it is not necessary to wait. Instead, it can save the states of the current work and continue to do another work, that is, to pursue another

goal in another transaction. After the child agent reaches its goal, it will notify its parent agent. The parent agent will then restore the saved work and continue to pursue this goal.

In summary, through Goal Net split, agents can be identified; and the agent coordination can be derived naturally through the original Goal Net structure. The coordination derived from this process reflects the fundamental dependency among the agents.

5.2 Agent Coordination in the e-Forecasting System

In the last section an agent-based e-forecasting system consists of four agents identified using the proposed method is described. In this section, an experiment is presented to show how the agents in the e-forecasting system cooperate together to generate forecasting results.

According to Figure 4, the data collection agent will be required to collect data by the forecasting service agent. The training agent will train the forecasting agent and finally the forecasting agent will be required to generate forecast results. However, if the forecasting agent has been trained, the forecasting service agent will require the forecasting agent to generate forecast results directly. Figure 6 shows the collaboration diagram of the agents. In Figure 6, besides the collaboration between the forecasting service agent and the other three agents as discussed above, there are also collaboration between the training agent and the data collection agent, the forecasting agent respectively. This is because the goal net of the data collection agent is re-used in the goal net of the training agent for data collection while the goal net of the training agent is re-used in the goal net of the forecasting agent for forecasting model training.

In our agent platform, agents are generated by an agent generator. Therefore in Figure 6, another agent, agent generator, is used to create the four forecasting agents as demanded by the forecasting service agent.

In the experiment, the developed e-forecasting system was used to forecast the exchange rate of US dollar to Singapore dollar. The forecasting model is a neural network model. The meta-data of the neural network structure, preset parameter values and initial means, variances, weights including rule values were stored in the knowledge base. The 50 training data sets were stored in the database. Three simple web pages for the three input variables were created respectively to simulate the real world situation. Each page contains one set of testing data. Another program was running in the background updating the three web pages every 30 minutes using the other 19 testing data sets.

The data collection agent monitored and checked the web pages at intervals of 20 minutes. The forecasting agent would be trained by the training agent using the training data in the database collected by the data collection agent. Then the forecasting agent could generate the forecasting results using the collected testing data from the web pages.

The objective of the experiment is to test how the agents cooperate with each other to produce the forecasting results for a user. In order to monitor the coordination and the cooperation of the agents, print statements were added in the agent programs. Whenever an agent receives a message or sends a message, the content will be output to a flat file.

From the log files, the coordination and cooperation among the five agents can be observed. The e-forecasting service agent sent a request to generate the data collection agent. The agent generator created the agent and notified the e-forecasting service agent. Then the e-forecasting service agent sent a request to the data collection agent. After the data were collected, the data collection agent informed the e-forecasting service agent. Then the e-forecasting service agent sent a request to the agent generator to generate the training agent. The agent generator created the agent and notified the e-forecasting agent. Then the training agent sent a request to the data collection agent. After the training agent got reply from the data collection agent it sent a request to the forecasting agent but got an error (the agent did not exist). Then the training agent sent the error message to the e-forecasting service agent. The e-forecasting service agent sent the agent generator to create the forecasting agent. Then the training agent sent request to the forecasting agent for forecast result. The forecasting agent generated the forecast result and sent back to the training agent. This procedure repeated until the last training data was used. Then the training agent sent a message to the e-forecasting service agent. The e-forecasting service agent then sent a request to the forecasting agent to generate the forecast result for the user request. The forecasting agent sent back the forecast result to the e-forecasting service agent.

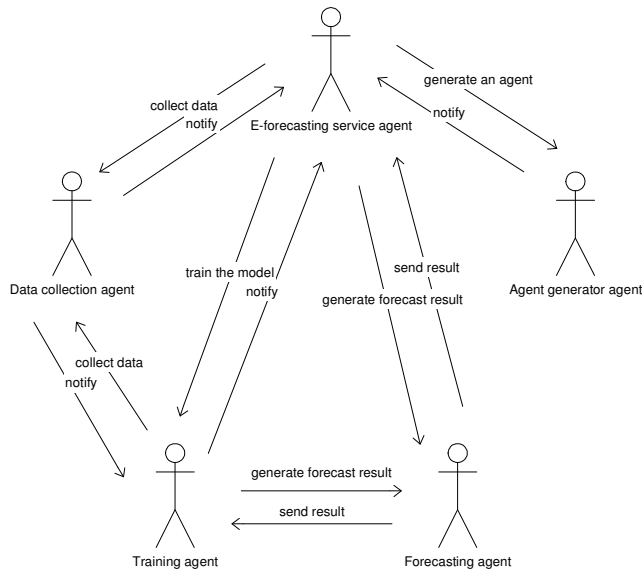


Figure 6. The agent collaboration diagram

The experiment results show that the e-forecasting service agent coordinated the whole process. The training agent cooperated with the data collection agent and the forecasting agent towards its own goal. The agents worked collaboratively and finally generated the forecast result for the user.

6. EVALUATION AND APPLICATIONS

To evaluate the proposed approach with existing multi-agent engineering methodologies, we extended Kavi's comparison framework [4] with the properties listed in Table 1.

Agents are goal oriented. It is nature to use goal-oriented approach for modeling/engineering multi-agent systems. Goal Net not only serves as an agent mental model but also provides a novel goal oriented approach to addressing agent identification,

organization and coordination in an integrated process in modeling/engineering multi-agent systems. Existing agent oriented software engineering (AOSE) methodologies [2, 3, 12, 13] lack the support of agent mental mechanisms. More over, they address the issues of agent identification, organization and coordination separately and partially.

Table 1. The evaluation of the method

	Gaia	MaSE	Agent UML	Tropos	Goal Net
Agent Mental Mechanism	No	No	No	No	Yes
Agent Identification, Organization and Coordination	Partial	Partial	Partial	Partial	Full
Implementation Toolkits	No	No	Yes	Yes	Yes
Connection between Mental Model and Implementation	No	No	No	No	Yes
Required expertise	High	High	Medium	High	Low
Decomposition	Yes	No	No	Yes	Yes
Design Re-combination	Low	No	No	Low	High
Integration	No	No	No	No	Yes
Goal-Oriented	No	No	No	Yes	Yes
Agent-Oriented	Yes	Yes	Yes	Yes	Yes
Automated AOSE	No	No	Partial	Partial	Partial

The practicability of the proposed approach has been shown by its implementation toolkit, which has been used in engineering various multi-agent systems in different application domains. Compared with the existing multi-agent system engineering methodologies, it presents an integrated solution for agent identification, organization and coordination. More over, it requires low agent expertise. The decomposability and reusability of goal nets make the proposed approach to have rich ability to address the problem decomposition and goal net re-combination. Furthermore, the proposed approach also supports the integration with existing agent systems. Using the proposed approach and its supporting toolkits the agent development has been simplified into three processes, designing goal net with goal net designer, creating dummy agents with agent creator, and loading goal net into agents.

Besides the e-forecasting system introduced in the paper, the proposed approach has been used in engineering various multi-agent systems in different application domains, including e-learning system [7], integrated manufacturing systems and services [6], and bio-manufacturing [9], etc.

7. CONCLUSION

Agent identification, organization and coordination are coherent processes in engineering a multi-agent system. Therefore these issues should be addressed in an integrated approach. In this paper, a novel method based on Goal Net, for addressing agent identification, organization and coordination in a coherent process is presented. The advantages of the new method are that agents

can be identified and organized coherently through Goal Net split and the coordination relations can be further derived at the same time. The proposed method, as part of the goal oriented (GO) methodology for engineering agent based system, has been successfully used in various applications in different application domains. Compared with the existing agent oriented methodologies, the proposed approach is not only practical but also promising.

8. REFERENCES

- [1] Armstrong, J. S. Standards and practices for forecasting. In *Principles of Forecasting: A Handbook for Researchers and Practitioners*, Kluwer Academic Publishers, Norwell, MA, 2000.
- [2] Bauer, B., Bergenti, F., Massonet, P. and Odell, J. Agents and the UML: A Unified Notation for Agents and Multi-agent Systems? *AOSE*, 2001, 148-150.
- [3] Bresciani, P., Perini, A., Giorgini, P., Giunchiglia, F. and Mylopoulos, J. Modeling Early Requirements in Tropos: A Transformation Based Approach. *AOSE*, 2001, 151-168.
- [4] Kavi, K. A Case for Agent-Oriented Software Engineering. <http://www.csrl.unt.edu/~kavi/Research/AOSE.pdf>.
- [5] Kolp, M., Giorgini, P., and Mylopoulos, J. A Goal-Based Organizational Perspective on Multi-Agent Architectures. In *Pre-proceedings of the Eighth International Workshop on Agent Theories, Architectures, and Languages (ATAL-2001)*, (2001), 146-158.
- [6] Kuay, C. S., Shen, Z. Q., Gay, R. and Miao, C. Y. Goal Net Agent Framework for Web Service Integration. In *Proceedings of the IASTED International Conference on Web Technologies, Applications, and Services (WTAS 2005)*, Calgary, Alberta, Canada, July 4-6, 2005.
- [7] Li, D. T., Shen, Z. Q., Miao, Y., Miao, C. Y. and Gay, R. A Goal Oriented E-Learning Agent System. *Lecture Notes in Computer Science (Intelligent Agent Technology and Applications II)*, Vol. 3681, Springer, 2005, 664 – 670.
- [8] Park, K., Kim, J. and Park, S. Goal Based Agent-Oriented Software Modeling. In *Proceedings of the 7th Asia-Pacific Software Engineering Conference (APSEC'00)*, Singapore, December 05-08, 2000.
- [9] Shen, Z. Q., Gay, R., Miao, C. Y., Tan, T. W., Kuay, C. S. and Lee, H. M. Process Modeling and Automated Execution for Bio-Manufacturing. *International Journal of Information Technology*, Vol. 12, No. 1, 2005, 37 – 48.
- [10] Shen, Z. Q., Gay, R., Miao, C. Y., and Tao, X. H. Goal Oriented Modeling for Intelligent Software Agents. In *Proceedings of the 2004 IEEE/WIC/ACM International Conference on Intelligent Agent Technology (IAT'04)*, Beijing, China, September, 20-24, 2004.
- [11] Shen, Z. Q., Li, D. T., Miao, C. Y., and Gay, R. Goal-oriented Methodology for Agent System Development. In *Proceedings of the 2005 IEEE/WIC/ACM International Conference on Intelligent Agent Technology (IAT'05)*, Compiegne, France, September 19 - 22, 2005.
- [12] Wood, M. and DeLoach, S. A. An Overview of the Multiagent Systems Engineering Methodology. *Agent-Oriented Software Engineering*, Lecture Notes in Computer Science, Vol. 1957, Ciancarini, P. and Wooldridge, M., Eds., Springer Verlag, Berlin, January 2001.
- [13] Wooldridge, M., Jennings, N. R., and Kinny, D. The Gaia Methodology for Agent-Oriented Analysis and Design. *Autonomous Agents and Multi-Agent Systems*, 3(3), 2000, 285-312.
- [14] Zhang, H., and Lesser, V. A Dynamically Formed Hierarchical Agent Organization for a Distributed Content Sharing System. In *Proceedings of the International Conference on Intelligent Agent Technology (IAT 2004)*, IEEE Computer Society, September 2004, 169-175.
- [15] Zhang, X. Q., Raja, A., Lerner, B. Integrating High-Level and Detailed Agent Coordination into a Layered Architecture. *The workshop on Infrastructure for Scalable Multi-Agent Systems, Agent's 2000*, 2000.