Open Giant Intelligent Information Systems and Its Multiagent-Oriented System Design

Longbing Cao[(a)], Chunsheng Li[(a)], Chengqi Zhang[(a)], Ruwei Dai[(b)]
(a) Faculty of Information Technology, University of Technology, Sydney
PO Box 123, Broadway, NSW 2007, Australia
[(b)]AI lab, Institute of Automation, Chinese Academy of Sciences, Beijing
PO Box 2728, Zhongguancun Donglu, Beijing, China,100080
{lbcao, csli, chengqi}@it.uts.edu.au, ruwei.dai@mail.ia.ac.cn

Abstract

Open giant intelligent information system has been died as a new field of complex intelligent information systems. In this paper, we mainly discuss about system design of this type of complex software systems. We first introduce system complexities, and then we discusse the applicability of multiagent-based approach for building open giant intelligent information system. A multiagent system computing model based on multiagent society frameworks and agent component patterns is proposed for constructing multiagent-oriented open giant intelligent systems. Then, we present a case study taking macroeconomic decision making as an instance of open giant intelligent information system. We discuss its system structure, decision-making mechanism, and system experiments. Our work shows multiagent-oriented open giant intelligent system on the basis of methodology of metasynthesis works well and effectively.

1. Introduction

As a type of complex software systems, open giant intelligent information system is climbing up the r ɹch schedule of complex intelligent information systems. Complexity of an open complex system is embodied in its distribution, globalization and interaction, as well as human involvement. Information system built to deal with open complex problem is very complex and network-oriented. For dealing with the above problem, it is unsuitable to build an autonomous intelligent information system that is simply composed of today's computers. A feasible and effective way is to combine human qualitative intelligence which cannot be simulated by current computers with quantitative intelligence which can be efficiently simulated by computers[1], and build an open giant intelligent information system(OGI^{2}S)[2], which is actually a human-computer-cooperated intelligent information system[2,3].

As for how to build an open giant intelligent information system, many computing paradigms, such as object-oriented analysis and design, component-based analysis and design, have been testified, and met with some critical problems emerging from complexities of open giant intelligent information systems. Multiagent technology[4,5] has been taken as a new paradigm for dealing with complex systems and as the next milestone in software development. Agents may show abilities of autonomy, intelligence, reactivity, mobility and collaboration, as well as facilities for human-computer interaction.

In the interest of building agent-based complex software systems[6], more and more researchers in agent field recognize the importance of organizational abstraction[7,8]. However, most of the researchers take the agent roles and its relationships as the focus of the abstraction; as a result, the organizational abstraction has actually been a process of modeling of organizational roles. In this case, the organizational abstraction has been a role-oriented abstraction, skipping the sociality of an MAS.

Among all system complexities of open giant intelligent information system, society and human involvement are two unavoidable internal elements, which bring new, open subjects for software researchers. In order to deal with the above complexities, we proposed social abstraction for agent-oriented open giant intelligent information systems[9,10]. In that case, a new methodology of agent-oriented abstraction, an agent-based open giant intelligent information system as an artificial multi-agent society, and social interactions as a unified interaction mechanism in multi-agent system, are proposed as some basic theories for building agent-oriented open giant intelligent information system[10].

In this paper, we first introduce this type of specific giant intelligent system and its characteristics. Then, we discuss the applicability of agent-based open giant intelligent information system in section three. In section four, a new multiagent society frameworks/agent component patterns-based computing model is proposed for building multiagent-oriented open giant intelligent information system. In section five, we present a case study of multiagent-based macroeconomic decision making based on a new methodology proposed specially for dealing with open giant complex systems. Section six summarizes our major work and provides indications for further research.

2. Complexities of Open Giant Intelligent Information Systems

As a special kind of complex software systems, open giant intelligent information systems [9] show following specific characteristics:

If the number of basic components or subsystems is extremely large (e.g. thousands to trillions), then the system is called a giant system. If there are a large variety of subsystems with a hierarchical structure; and the interactions between basic components and basic components, basic components and subsystem, basic components and environment, subsystem and subsystem, subsystem and environment are represented by some mathematical formula, such as nonlinear functions, or by a communication protocol, then the aggregate is called a complex giant system. In addition, if an intelligent information system and its subsystems exchange energy, information or material with environment, it is called an open giant intelligent information system.

For an open giant intelligent information system, the intelligence emerged at the system level is not equal to the addition of that of its individuals, it is an emergence of interactions among components and environment. As a result, an OGI^2S shows certain anti-intuition characteristics, such as the paradox, self-reference, unstability, uncomputability, interrelationship, and emergence, which is called "surprise-growing mechanisms"[11]. Complexities of an OGI^2S come from its societal characteristics, which result in various kinds of unpredictable outcomes. The system complexities of OGI^2S are further shown as follows.

Open: there are exchanges of energy, information or material in a system and among a system and its environment. The open environment is the most complex and common kind of environment, which is inaccessible, nondeterministic, and dynamic[12], the subsystems or components acquire knowledge through adaptive learning during the interactions.

Hierarchical: there are many different levels existed from components, which are clearly recognized in individual level, to system in terms of the macro level. For some cases, it is not clear how many levels there are in a system. On the other hand, there are various types of organizational structures in a system and its subsystems, for instance, the peer, hierarchical, matric, loop, or linear; or even to the extent that it is not clear what the structure is, such as a combination of some basic patterns.

Social: a system is made of social agents, which are shown to be autonomous, parallel, distributed(of data, logic, or subsystems), and flexible. Components with specific roles cooperate, interact, and undertake problem-solving through certain communication language based on specific(local or global) organizational rules(e.g., social rationality principle).

Evolutionary: it is not easy to determine the runtime exchange, interaction, and behaviors of the components, subsystems, and system at design time; some unpredictable characteristics or status at the system level may emerge from the partial units and incomplete information after some period, such as some self-organization patterns, etc.

Human-computer-coexisted: the problem cannot only be solved by machines autonomously; or in other words, human beings has been one constitute part in an OGI^2S, and serves as the key element of the problem solving for his and the collective commonsense knowledge and thinking in images.

As a typical instance of OGI^2S, the Internet is a large-scale, distributed, dynamic, and evolutionary intelligent information system, which is consisted of users and computer systems[13].

3. Applicability of agent-oriented open giant intelligent information systems

As for the above complexities of OGI^2S, the computing models currently available for building complex information systems, such as the object-oriented computing, the component-based computing, etc., can be used to do limited things for dealing with OGI^2S.

Multi-agent, being advocated as model of the next generation for constructing complex, distributed systems[4], are advanced as an overarching framework for bringing tighter the component AI sub-disciplines that are necessary to design and build intelligent entities. It is argued that analyzing, designing, and implementing complex software systems as a collection of interacting, autonomous agents (that is, as a multiagent system) affords software engineers a number of significant advantages over contemporary methods[6]. Furthermore, it is empirically shown that (i) the agent-oriented decompositions are an effective way of partitioning the problem space of a complex system; (ii) the key abstractions of the agent-oriented mindset are a natural means of modeling complex systems; and (iii) the agent-oriented philosophy for modeling and managing organizational relationships is appropriate for dealing with the dependencies and interactions that exist in complex systems[6].

Moreover, the concepts of agent provide following five facilities for dealing with OGI^2S. (i) Loose abstraction of granularity. The coarse-grained abstraction provides flexible mechanism for modularizing and managing the organizational relationships and structures of an OGI^2S, and for designing the interactive patterns of agents. (ii) Autonomous problem-solving and runtime decision-making. This is the key power of agent exhibiting the goal-directed behaviors for dealing with the open, unexpected, and evolutionary situations; this strategy simulates the internal laws of the evolution process of the real world, and provides the possibility and mechanism for dealing with the difficulty of decomposing an OGI^2S. (iii) Integrated computing architectures and mechanisms. Agent combines multiple computing architectures and mechanisms for flexibly generating, maintaining, and managing agent organizations, such as logic-based abstraction, behavior-based interactions, connectionism, etc. (iv) Social interactions among agents. Agent supports multiple types of interactions, such as cooperation, negotiation, coordination, competing, commitment, or alliance between agents and agents, agents and environment. This is powerful for simulating the complicated organization and role relationships in an OGI^2S. And, (v) human agent interaction. Agent provides techniques, such as interface agents, intentional stance of agents, which make it possible for creating a human agent coexisted and cooperated problem-solving virtual world.

Thus, it can be seen that multi-agent embodies potentials of abstraction and computing mechanisms for coping with complexities of OGI^2S. It is suitable and feasible for agent-oriented paradigm to be taken as the computing model of OGI^2S.

4. Multiagent society frameworks and agent component patterns-based OGIS engineering

Multi-agent technology provides a new paradigm and a possible technical means for implementing open giant intelligent information system engineering. On the other hand, for complexities emerging from this new type of especially complex intelligent system, computing models popularized currently, like object-oriented and component-based computing, still have too many problems related to characteristics of openness, sociality and human-computer coexistence to deal with.

Based on theory and practice experiences of object-oriented and component-based network engineering, and studies in emergent complexities of open giant intelligent system, we propose and testify a new computing pattern, namely multiagent society frameworks and agent component patterns-based open giant intelligent system engineering.

A framework or pattern represents the same or similar information or knowledge which can be observed or reused at time or space dimension; they can be further classified in terms of some methods. It is also true that there are same or similar society frameworks and component patterns in multiagent-oriented OGI^2S, each corresponds to different granularities and levels of abstraction: (i) a society framework represents common properties at macro-level of agent society; however, (ii) a component pattern focuses on the general things showing at the agent-level.

4.1 Multiagent society frameworks

A multi-agent system is an artificial organization, or named a multi-agent society, which is viewed as a composition of an MAS organization and its environment. The more complex an MAS is, the more obviously society frameworks and relationships emerge. In the case of the societal information in an MAS, an society framework may be nominated as partially or globally logical relationships, topological structures or control mechanism, which exhibits same or similar information in a specific problem domain. The possible forms of an organizational scheme in a specific problem domain includes: (i) software architecture of an MAS; (ii) organizational structures or relationships existed in an MAS, such as the self-organizational and evolutionary ways; (iii) structures and relationships between MAS organization and its environment; (iv) same or similar features emerge at the branch level (e.g., group, sub-system) of the society; (v) interaction mechanisms and norms existed at the societal level.

4.2 Agent component patterns

Component patterns of an MAS focus on: (i) component creational patterns: such as the type, role, and attribution that an agent embraces, etc.; (ii) some basic structures of a type of agents; (iii) interaction patterns between agents, such as how an agent cooperates with its partners; (iv) interaction patterns between agent and its environment. The following pitfalls should be avoided when studying or designing the component patterns of MASs: (i) applying the object-oriented design patterns[14] mechanically in an MAS; (ii) thinking that the granularity of an agent should be as fine and fixed as possible; (iii) defining the agent patterns from the aspect of individual level.

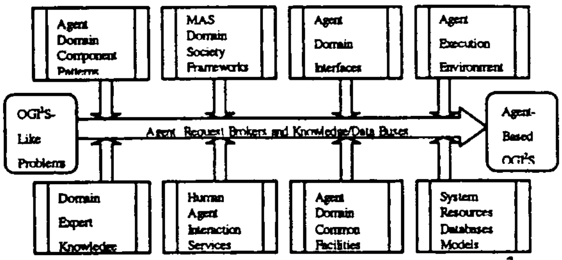

Figure 1 Assemblage of agent-oriented OGI²S

A kind of social agent computing based on agent society frameworks/component patterns may emerge in analysis and design of agent-oriented OGI²S, which is on the basis of an established catalogue and libraries of society frameworks and component patterns in a specific problem domain. In this case, the development of an agent-based system looks more like a process of assemblage of agent components and its society frameworks, plus some user specific customization, which just looks like finished at the software factories: first, determining the reusable agent components according to a specific society framework; then, specializing the chosen agents and its society framework, and developing specific types of agents according to the problem domain; finally, assembling an MAS with certain frameworks, components and specific agents out of the above systems (as shown as the figure 1).

5 Case study: a multiagent-based macroeconomic decision support system

In this section, we'd like to introduce our experimental work about multiagent-oriented open giant intelligent information system taking a macroeconomic decision making as an instance[15]. We build this system based on a methodology specially proposed for analysis and design of open giant complex systems.

Macroeconomic decision making is a very complex problem, which involves multiple domain specific knowledge, expertise and work processes. In our studies of this problem, we deal with it using a new methodology proposed for coping with complexities of open giant intelligent systems in particular, namely metasynthesis from qualitative to quantitative [1]. Furthermore, in order to build a practical system supporting macroeconomic decision making, we utilize the technical method, hall for workshop of metasynthetic engineering (HWME), dvanced specially in respect of the above methodology ?]. We call our new system for decision making as a ıetasynthetic decision support system [16].

5.1 System structure of agent-oriented macroeconomic decision support system

In terms of our extended n-tier client/agent/server-embedded Requestor-Mediator-Provider computing model and structure of the network-based HWME for macroeconomic decision-support [3], Fig. 2 illustrates a framework and its working mechanism of the agent-based open giant intelligent system for macroeconomic decision making. This system is distributed at more than six sites over the Internet. Each site is expected to be an Intranet or located at an Intranet. We use IBM mobile agent platform Tahiti and Aglet class[1] as our agents' server and father class.

The following classes of agents are dwelled in the hall space.

1) Role Agent: This is a Java-based extension of Aglet class and is a representative of an expert, chairman, or an administrator in the HWME, which embodies a human beings' intention through interaction with related interface agents; each role agent has specific authorities, functions, and related resource services, and may take master or slave, private or public form. A master role agent can create a slave agent and dispatch it to another agent server.

2) Interface Agent: This provides customized interfaces for different role agents, including discussion templates, discussion scripts, discussion records, visual data analysis tools, resources invocation and parameters input, report display and output, etc.

3) Administrator Agent: This resides at the site of the Mediator on which the chairman is situated, and is responsible for registering the resources and applications services broadcasted by the Provider sites, creating and managing life cycles of mobile agents, and maintaining the business logic of the system. It also takes charge of filtering and decomposing services requests, forwarding each request to related database or application server; it will integrate every individual response on demand and transfer the synthesized result to the target applicant.

4) Coordinator Agent: This agent, of a Java-based extension of Aglet class, is created individually or in the form of a mobile package within the context of the Role agent, Interface agent, Administrator agent, or Service agent, and then dispatched to another site. It is responsible for transferring user requests, such as database operations, information searching, or services broadcasting, to the target servers, and handing in user requests to service agents or DBMS gateway agents for dealing with application execution or database operations.

[1] IBM Aglets Workbench Page: http://www.trl.ibm.com/aglets/.

After finishing execution, the coordinator will transfer the response result to the user; it then might migrate to another site according to task requirements or the situated condition autonomously after finishing user request.

5) Service Agent: This is a Java-based extension of Aglet class. Applications of models and methods for macroeconomic forecasting and warning, and consensus-building applications are agentized and packed as an agent or agent package. A service agent accepts and executes the service-calling request transferred by incoming coordinator agent, and returns the response result through the waiting coordinator agent or a message.

6) DBMS Gateway Agent: This is situated at every database server statically, and is responsible for informing incoming coordinator agents, which carry database requests, of information about data sources and JDBC driver available, and assisting coordinators in database operations. This agent resides at the sites of the macroeconomic database, the system database and the document base of the HWME.

5.2 System decision-making mechanism

This system can be built based on a browser/server (which takes the FijiApplet class as the abstract class of applet) or a client/server computing model in Java. For users' widespread access, we recommend the former. Economic experts can log on the web server and join the opening discussion in the hall space after credential authentication through a Java-enabled browser on the Internet. An encyclopedic chairman is situated at the Mediator, whose deputy, the chairman role agent, creates and dispatches mobile coordinator packages, which contain some necessary tools and services, to the Requesters and Providers before the beginning of a discussion, respectively; administrator agents on the Mediator registers online services information broadcasted actively by all Providers through coordinators.

After finishing all initialization, the chairman person declares startup of discussion and broadcasts topics, e.g., *Forecasting of Gross National Products 2002*, to all joining experts. All online experts make qualitative statements, talk and even debate about certain arguments with each other through their own role agents created and dispatched by relevant interface agents; they call or create some real-time macroeconomic forecasting

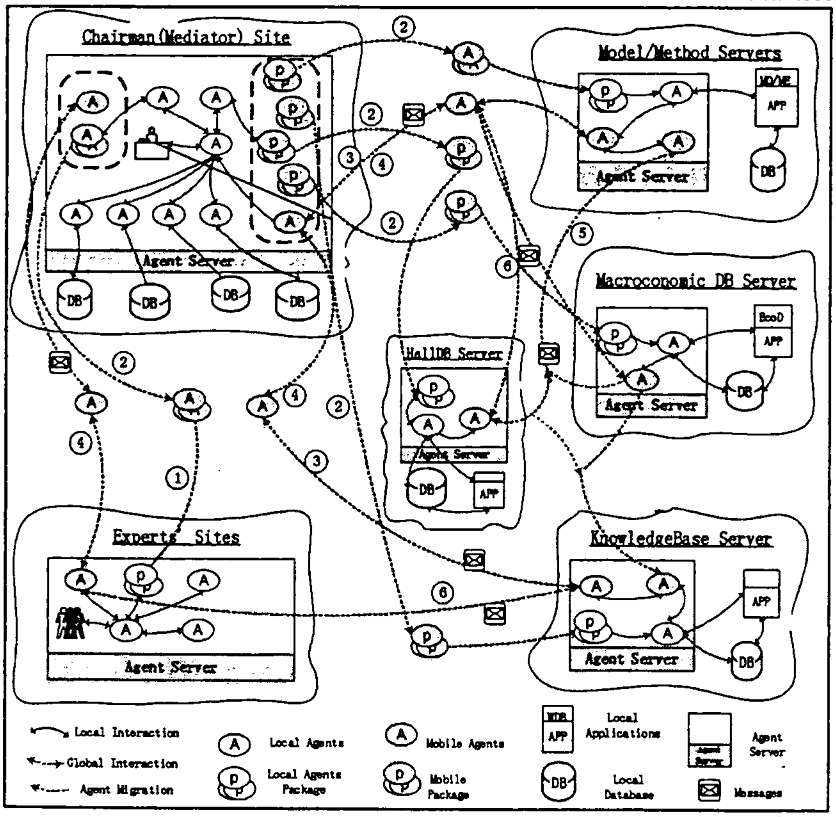

Fig.2 System structure of multi-agent-based macroeconomic decision support system

model or method service agents as needed, input values of parameters, and present returned results to the discussion hall to prove that their suggestions or arguments are correct.

Sometimes, several inconsistent or even cliff-hanging remarks coexist in the discussion, and none of them can supersede all other ones; at this time the discussion goes into another phase, some kind of consensus-building agents should be invoked to unify all incompatible arguments or put them in order for further discussion.

After some recursive loops of discussion, the chairman would synthesize one or more conclusions or solutions for further discussion, declare the beginning of decision phase, and broadcast the above conclusions or solutions for decision-making. Then, experts would begin their quantitative discussion on the basis of the present outcomes of qualitative discussion under the guidance of the chairman, invoke or build applications of models online to verify their viewpoints, and eventually cohere to one conclusion or create an ordered solution list for decision-support.

5.3 System experiments

To demonstrate the proposed framework and the workflow of the multiagent-based HWME, a test prototype was set up in Java, which is based on the above 3-tier client/agent/server-nested Requester-Mediator-Provider architecture. This system is composed of one chairman side which acts as the Mediator, several expert client sides whose interfaces and some tool agents are created and sent out by the Mediator, and five kinds of resource service sides in TXT texts, Access 2000, and SQL Server 2000, DB2 7.2 and Oracle 9i, respectively. We programmed Aglet-extended agents, an IBM Tahiti server[11] should be preinstailed and started up before the system execution on each side.

The chairman starts the system, creates and sends out mobile packages to client sides. After arrival on the destinations, the package is unpacked, a client interface shows up; the chairman then advertises the discussion title to all participators through his slaves. The experts attend the discussion through the client interface agent, they can choose other online experts to open and control a private discussion group through creating and dispatching private agents if they think it is necessary. The chairman or the experts can transfer information to or coordinate with target ones through slave or messenger agents.

For convenience of accessing resources, each resource server has a stationary DBMS gateway agent, which listens for incoming access requirements and parameters of the DB data source. As soon as a client invokes the data access module, a resource access coordinator agent will be hatched and dispatched to the destination, the gateway agent on the resource server will notify the DB service agent of implementing the requested data operation, and then forwarding results to the incoming access agents.

In this system, in order to obtain better system performance, multiform working mechanisms must be flexibly unified, especially more attention should be paid to taking advantages of agent technology. Here we discuss some tested facets. Mobility is widely used for transportation of distributed computing entities, such as the client slave interfaces, data access agents, and the private agents. The mobile modes of agents should be adaptable to their environments. For instance, it is in parallel that mobile packages are dispatched to destination sides during initialization; it is also in the same way for chairman to multicast notification information to all. After arrival of mobile agents at their destinations, sufficient attention should be paid to the message-passing mechanism; many functions are performed by mobile agents through message-passing. For the modes of message-passing, asynchronous communication is used in global interaction between remote agents.

Multiple kinds of agent design patterns[11] should be configured and employed for optimizing the design and the performance of this system, for example, the master-slave pattern sample of task patterns, the itinerary of traveling patterns, and the messenger of interaction patterns.

In addition, mobile agents are hierarchical, i.e., a mobile agent(father agent) can spawn sub-mobile agents(child agents) as needed; some mobile agents can be containers of other agents, all these agents are organized hierarchically and dynamically in a container. Moreover, an Multiagent is an active component, which has certain autonomy and reactivity, it can adapt its itineraries and activities according to its dynamic network environment and task list. For instance, an agent will autonomously decide where to go and what to do next on condition that its target machine is down, the agent server of its destination is disabled or the database environment is changed.

6. Conclusions and future work

Open giant intelligent information system, as one type of special complex giant intelligent systems, brings us many open research problems both in theoretical and experimental sides. From methodology part, a methodology named metasynthesis from qualitative to quantitative has been advanced for dealing with special complexities emerging from this specific giant intelligent system. However, as for system design of a practical open giant intelligent information system, we still have long way to go.

One suitable way to construct an open giant intelligent information system is based on the multiagent technology, namely, an multiagent-based open giant intelligent information system. In this paper, we argued the multiagent approach is currently the most suitable computing paradigm for dealing with complexities of open giant intelligent information system.

In order to build multiagent-oriented open giant intelligent information system, we proposed a multiagent society frameworks/agent component patterns-based computing model. Based on this model, we constructed infrastructure of multiagent-based macroeconomic decision support system, which can be taken as an instance of open giant intelligent information system.

Through our analysis and design both in system structure, working mechanism and experiments, we testified our proposed multiagent-based approach for building open giant intelligent information system based on methodology of metasynthesis from qualitative to quantitative. Our work shows the above strategies work well and effectively.

For the complexities of open giant intelligent information system, and challenges emerging when we combining two immature fields, multiagent technology and open giant intelligent information system, we still have too many things to do with system design of multiagent-oriented open giant intelligent information systems.

Our future work includes but not limited to:

(i) Define and establish multiagent society frameworks and agent component patterns libraries for open giant intelligent information systems;
(ii) System computing models research for building multiagent-based open giant intelligent information systems;
(iii) Planning and interaction mechanisms in multiagent-oriented open giant intelligent information systems.

References

[1] X.S. Qian, J.Y. Yu, and R.W. Dai (1990). "A new discipline of science—the study of open complex giant system and its methodology"(in Chinese), *Nature Journal*, 1990, 13(1): 3-10.

[2] R.W. Dai, J Wang, and J Tian, *Metasynthesis of intelligent systems*(in Chinese). Zhejiang Science and Technology Publishing House, China, 1995.

[3] Longbing Cao, Ruwei Dai, "Human-computer cooperated intelligent information system based on multi-agents", *ACTA AUTOMATICA SINICA*, China, 2003, 29(1):86-94.

[4] M Wooldridge, "Agent-based software engineering", In *IEE Proceedings on Software Engineering*, 1997, 144(1):26-37.

[5] M Wooldridge, *An introduction to multiagent system*, Wiley, 2001.

[6] N.R. Jennings, "An agent-based approach for building complex software systems", *Comms. of the ACM*, 2001, 44(4):35-41.

[7] F Zambonelli, N.R. Jennings, M Wooldridge, "Organisational rules as an abstraction for the analysis and design of multi-agent systems", *Int J. of Software Engineering and Knowledge Engineering*, 2001, 11(3):303-328.

[8] P Panzarasa, N.R. Jennings, "The organisation of sociality: a manifesto for a new scienece of multi-agent systems", *Proc. 10th European Workshop on Multi-Agent Systems (MAAMAW-01)*, Annecy, France, 2001.

[9] Longbing Cao, Ruwei Dai. "Social abstraction for agent-based open giant intelligent systems", *International Conference on Intelligent Information Technology*, Beijing, *2002*, 47-52

[10] Longbing Cao, et al., "Open giant intelligent information systems and its agent-oriented abstraction mechanism", *Fifteenth International Conference on Software Engineering and Knowledge Engineering*, San Francisco, 2003(to appear).

[11] L Casti, *Would be worlds: how simulation is changing the frontiers of science*(in Chinese), Shanghai Science and Technology Press, 1996.

[12] C.G Hewitt, "Offices are open systems", *ACM Transactions on Offices Information Systems*, 1986, 4(3): 321-329.

[13] L.B. Cao, R.W. Dai, "Internet as a metasynthetic information system", *Pattern Recognition and Artificial Intelligence*, 2001, 14(1):1-8.

[14] E Gamma, et al., *Design patterns: elements of reusable object-oriented software*, Addison Wesley, Reading, 1995.

[15] Longbing Cao, Ruwei Dai, "On metasynthesis and decision making", *Journal of Computer Research and Development*, Beijing, 2003(to appear).

[16] L.B. Cao, R.W. Dai, "Autonomous intelligent agents-based metasynthetic engineering: a macroeconomic decision-support system", *First International Congress on Autonomous Intelligent Systems(ICAIS2002)*, Geelong, Australia, ICSC Academic Press, Canada/The Netherlands, 2002, 60-66.

[17] L.B Cao, R.W Dai, "Agent-oriented metasynthetic engineering for decision making", *International J. Information Technology and Decision Making*, 2003, 2(2).