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Human-Computer-Cooperated Intelligent Information System Based on Multi-Agents[1)]

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Abstract The Hall for Workshop of Metasynthetic Engineering (HWME) is an engeering technology proposed for coping with open complex giant systems. In this paper we describe the implementation of a human-computer-cooperated intelligent information system with HWME and multi-agents. We propose a layered model, a system structure over the network, and a distributed computing model—an n-tier client/agent/server-nested Requester-Mediator-Provider—for building the system. Furthermore, we discuss the framework and working mechanisms of an agent-based system of HWME, which is designed for macroeconomic decision-support based on intelligent information agents in Java. Our system implementation shows that an agent-oriented HWME system over the Internet may exhibit better performance in terms of handling open complex problems.

Key words Open complex problem, human computer cooperation, intelligent information system, HWME, multi-agent technology

1 Introduction

The research of open complex systems has been increasingly popular. 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. It is unsuitable to build an autonomous intelligent system that is simply composed of today's computers for dealing with the above problem. 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, and build a Hall for Workshop of Metasynthetic Engineering (HWME)[1,2], which is actually a human-computer-cooperated intelligent information system.

Agent technology has been taken as a new paradigm for dealing with complex systems and as the next milestone in software development, and has been popularized in research and development of many relevant areas for its advantages. Agents[3~5] may show autonomy, intelligence, reactivity, mobility and collaboration ability, as well as the facility for human-computer interaction. The Internet cyberspace and the Internet-related technology provide practical facilities and user-friendly way for constructing large-scale distributed systems. These technical achievements make it possible to build an agent-based human-computer cooperated intelligent system over the Internet, synthesizing human intelligence and powerful computer performance for complex problem solving.

The organization of this paper is as follows. In Sections 2 and 3, a layered model and a system structure of network-based HWME are presented respectively. In Section 4, a computing model, an n-tier client/agent/server-incorporated Requester-Mediator-Provider model, is proposed for building an HWME. Furthermore, in Section 5 we discuss and test the framework and its working mechanisms of an HWME for macroeconomic decision-sup-

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port, which is implemented in intelligent information agents. Section 6 summarizes our major work and provides indications for further research.

2 Layered model of a network-based HWME

The essence of metasynthetic engineering is to organically unify expert group, data and all sorts of information, and computer technology, as well as scientific theories of related disciplines and human experience and knowledge[1], which are required for problem-solving of an open complex system. Successful application of this approach depends on giving full play to the synergetic advantages of all the above factors. With the popularization of the Internet and the development of Internet-related technology, it is possible to identify an architecture of Internet-based HWME[6] and construct a network-based hall space.

A layered model of a network-based HWME is depicted in Fig. 1. According to this model, the HWME is composed of six layers from top down: Interface, Decision-making, Metasynthesis, Gateway, Resources Services and the Platform layer.

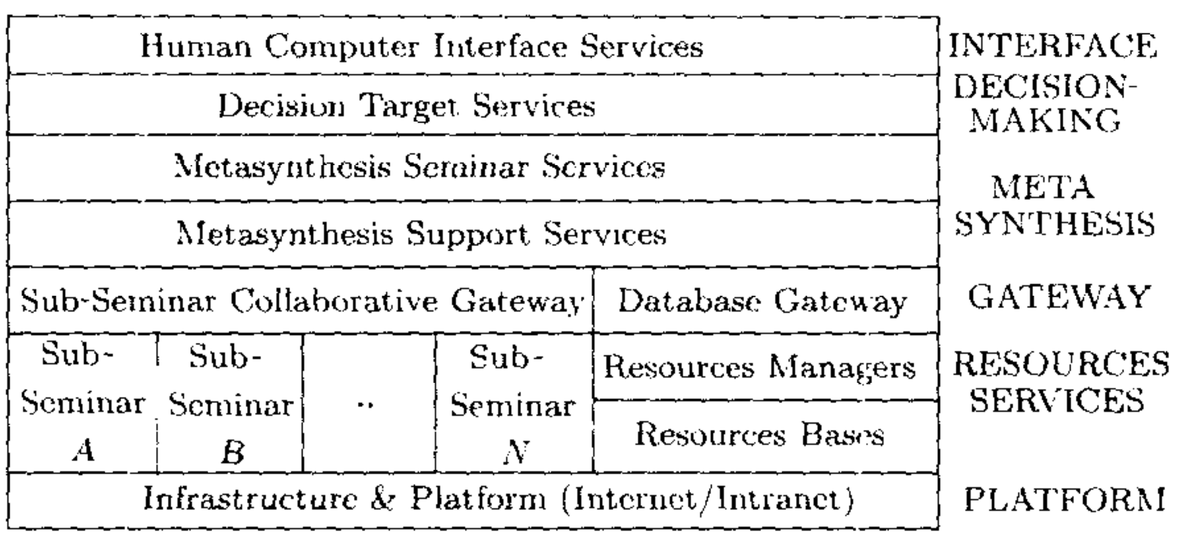

Fig. 1 Layered Model of a Network-based HWME

The Interface layer is an interaction place between human experts and computers, and provides a variety of user interfaces and result browsers, such as visual query tools, visual model-building tools, knowledge builder, data analysis tools, etc. The Decision-making layer works for decision objectives, e. g., monthly and yearly economic forecasting. The Metasynthesis layer provides Metasynthesis Seminar Services and Metasynthesis Support Services, which is a distinctive part of the HWME. Resource services required for the HWME include distributed databases and their management systems (DBMS), model/method bases and their management systems, and knowledge base and its management environment; some measures must be taken against integration and heterogeneous and distributed information. Multiple distributed sub-seminars (distributed HWMEs) with specific topics are integrated through the Sub-Seminar Collaborative Gateway. The current infrastructure of a network-based HWME consists of the Internet and some Intranets distributed at related organizations or branches.

3 System structure of a network-based HWME

In this paper, we take the macroeconomic decision-making as a requirement for problem solving. Obviously, it is a very important and complex problem. Our approach for dealing with this problem is to develop an HWME, which is a human-computer-cooperated intelligent information system, and takes economic experts in the workshop of macroeconomic decision-making as constituent components of the hall space. The system structure of the HWME should be distributive, interactive and hierarchical, and is recommended to be based on the Internet. We hope that the decision-making conclusions of the target subject emerge from complex interactions among three systems: a data and information system, a human expert system and a computer system.

During the last several years, for macroeconomic decision-support a network-based prototype has been built[6~9] in terms of the conception of human-computer-cooperated metasynthetic engineering, which is based on the Intranet/Internet computing model. Fig. 2 exhibits the system structure, whose implementation involves disciplines of computer science, artificial intelligence, knowledge discovery, etc.

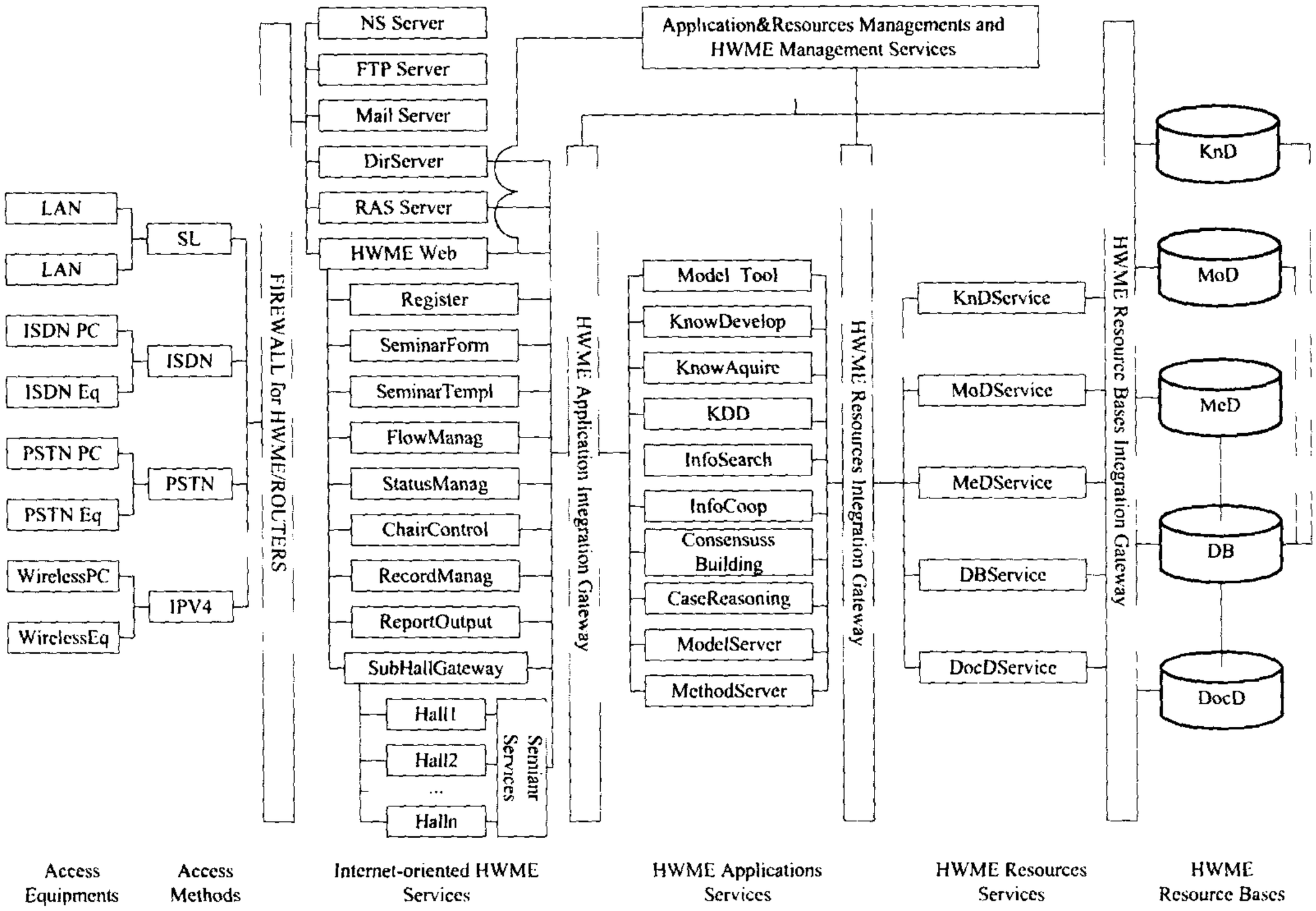

Fig. 2 Structure of the Newwork-based HWME

As a whole, the hall is made up of five centers: a metasynthetic support center which includes macroeconomic modeling and method systems, consensus-building applications, knowledge development environment, visual modeling system, and information search engines inside or outside the hall website; a seminar center, which provides different forms of discussion templates, script builders, distributed sub-seminars integrator, and management of discussion flow, system status, roles, discussion record and concluding report; a data center composed of distributed macroeconomic databases, system databases, and database management systems; a security center including firewalls, proxies, active intrusion detection, etc.; an information cooperation center, which integrates internal and external mail servers, notification system, BBS, schedule system, and office support system.

4 Distributed computing model for an HWME based on multi-agents

Multi-agent technology as a powerful computing paradigm has a joint ability of interaction-based and algorithm-based computing. Advantages of agent-based computation can be obtained by making full use of four combinations: combinations of algorithm and interaction, multiple types of agent technology, multiple design patterns, and of multiple working mechanisms.

In our project of agent-based HWME for macroeconomic decision-making, our strate-

gy is to encapsulate tasks, algorithms, interaction, management and database operations in macroeconomic decision-making with a type of agent named intelligent information agents(IIAgent) as needed. In this paper, intelligent information agents exhibit autonomy, mobility, flexibility, and ability of information integration and operation, which enhance the performance of distributed computation.

The underlying distributed computing model, an extended Requester-Mediator-Provider[10], and its working mechanism are illustrated in Fig. 3. In this scheme, the Requester deals with users' requests and responses, or user-system interaction; after accepting user requests it dispatches coordinator agents carrying the requests to the Mediator. The Mediator is the business logic center of the system, and the management center of mobile agents and global interactions; it may differentiate or decompose incoming requests in case of need, and transfers them to multiple relevant services on the Provider side, through mobile coordinator agents. The Provider may be composed of multiple resource services, such as databases, applications, etc. After responding users' requests, the executed results are returned to the Requester through a message-passing mechanism.

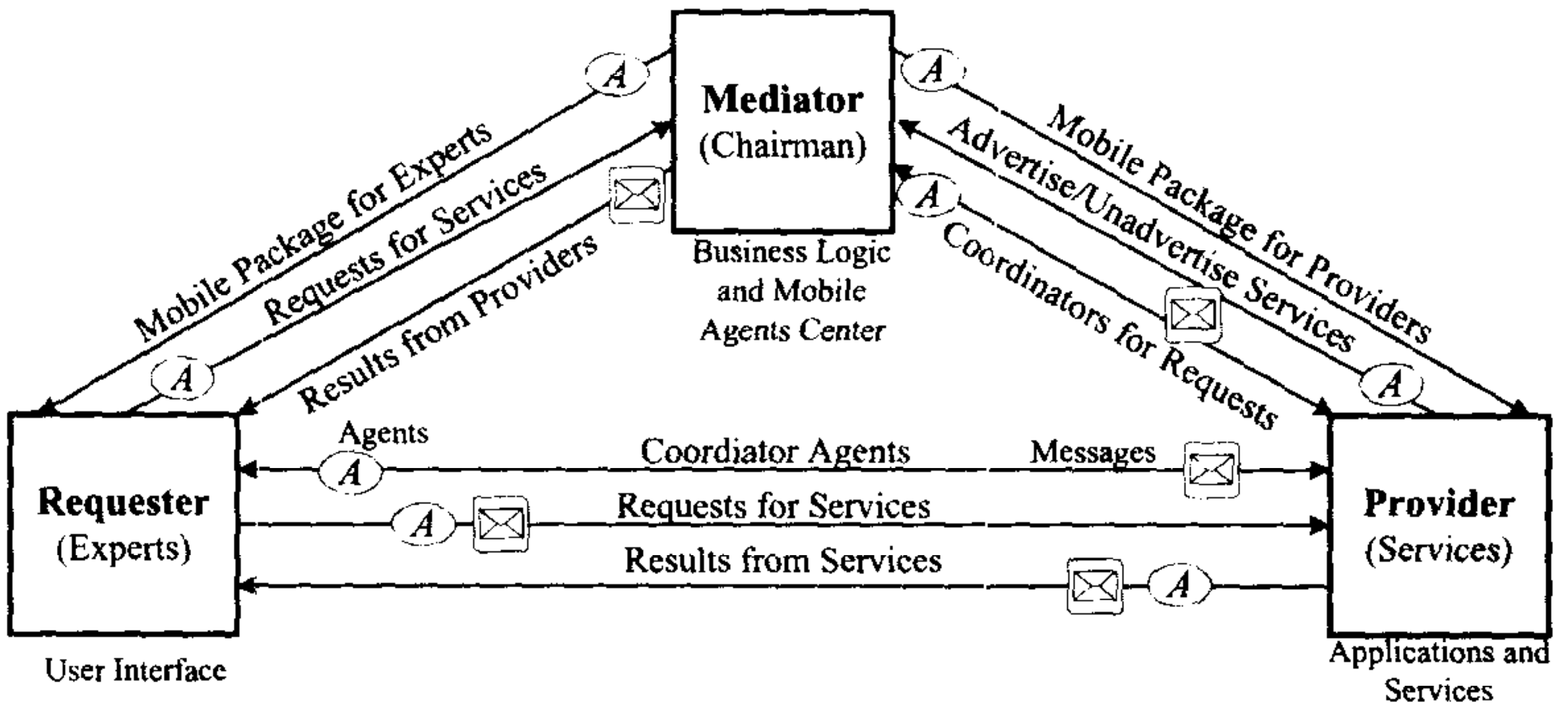

Fig. 3 Requester-Mediator-Provider Model

In this computing scheme, there are many administrator agents and (mobile) coordinator agents, which are staying at the Mediator, or created and then dispatched to other sites. All mobile agents for local interaction immigrate in a mobile package from the Mediator, and cooperate with local static agents or are forwarded to target servers for further tasks. The Mediator is the cradle of mobile agents, and the scheduler and the business logic center of the distributed resource integration system; it dispatches mobile agents to target nodes, maintains their proxies, itinerary plans and life cycles, registers resources and services broadcasted by the Provider, and mediates among requesters and providers for specific databases or application operations. The services on the Provider are actively broadcasted to the Mediator. A service can cooperate with its related partners through coordinator agents, and return results to requesters.

In order to ensure proper execution of added agents, an agent server should be preinstalled on each machine, and serves as the server of local computing model; stationary agents and the arrived ones make up a client tier, which are running over the agent server for local functions; the arrived coordinator agents for global interoperation function as an agent tier. For this Requester-Mediator-Provider architecture, some mobile agents are placed on the path from client to server for global interaction among these three tiers, as a matter of fact, they make a middle agent tier in the client/server model. Consequently, a client/agent/server computing scheme is embedded into the above Requester-Mediator-Provider model(see Fig. 4).

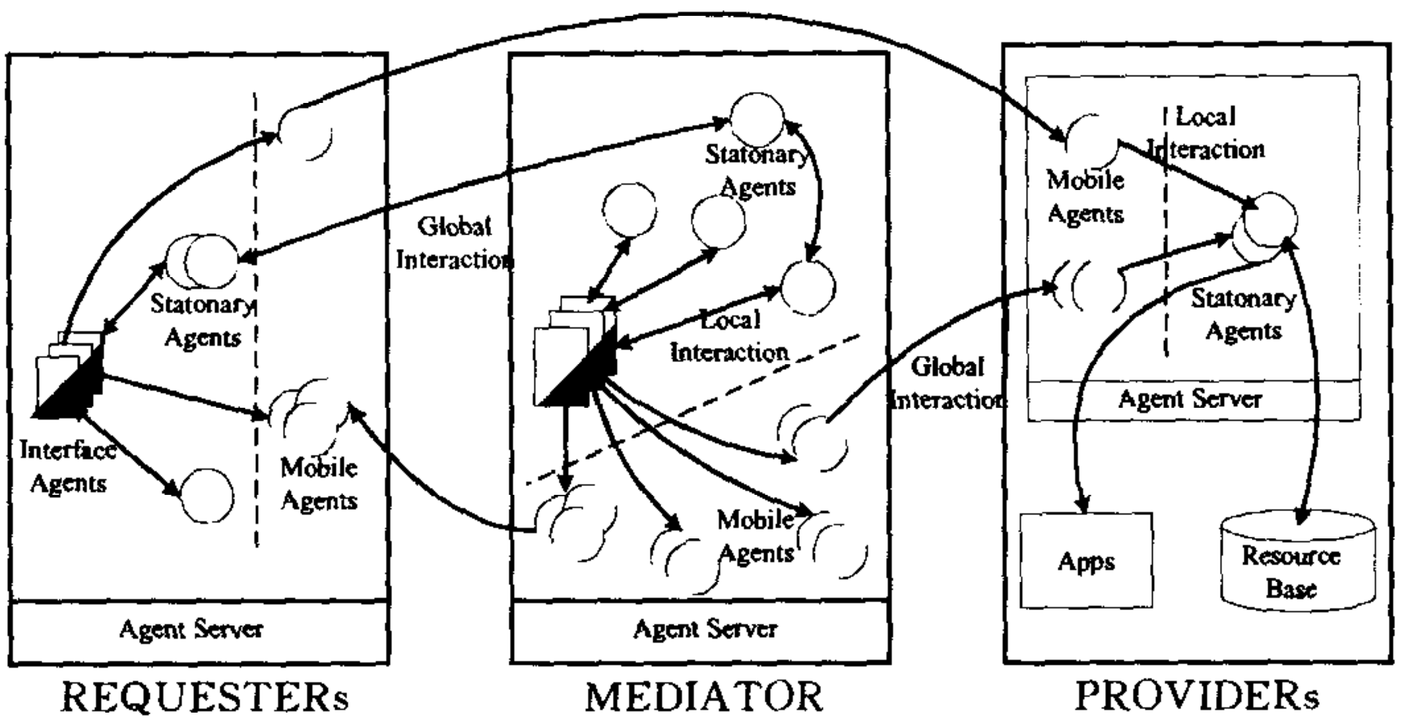

Fig. 4 N-Tier Client/Agent/Server-Nested Scheme

5 Framework and working mechanisms of a multi-agent-based HWME for macroeconomic decision-support

In terms of the above layered model and structure of the network-based HWME for macroeconomic decision-support, Fig. 5 illustrates a framework and its working mechanism of the HWME, which is implemented in IIAgents. This system is depicted to distribute to more than six sites through the Internet. Each site is expected to be an Intranet or

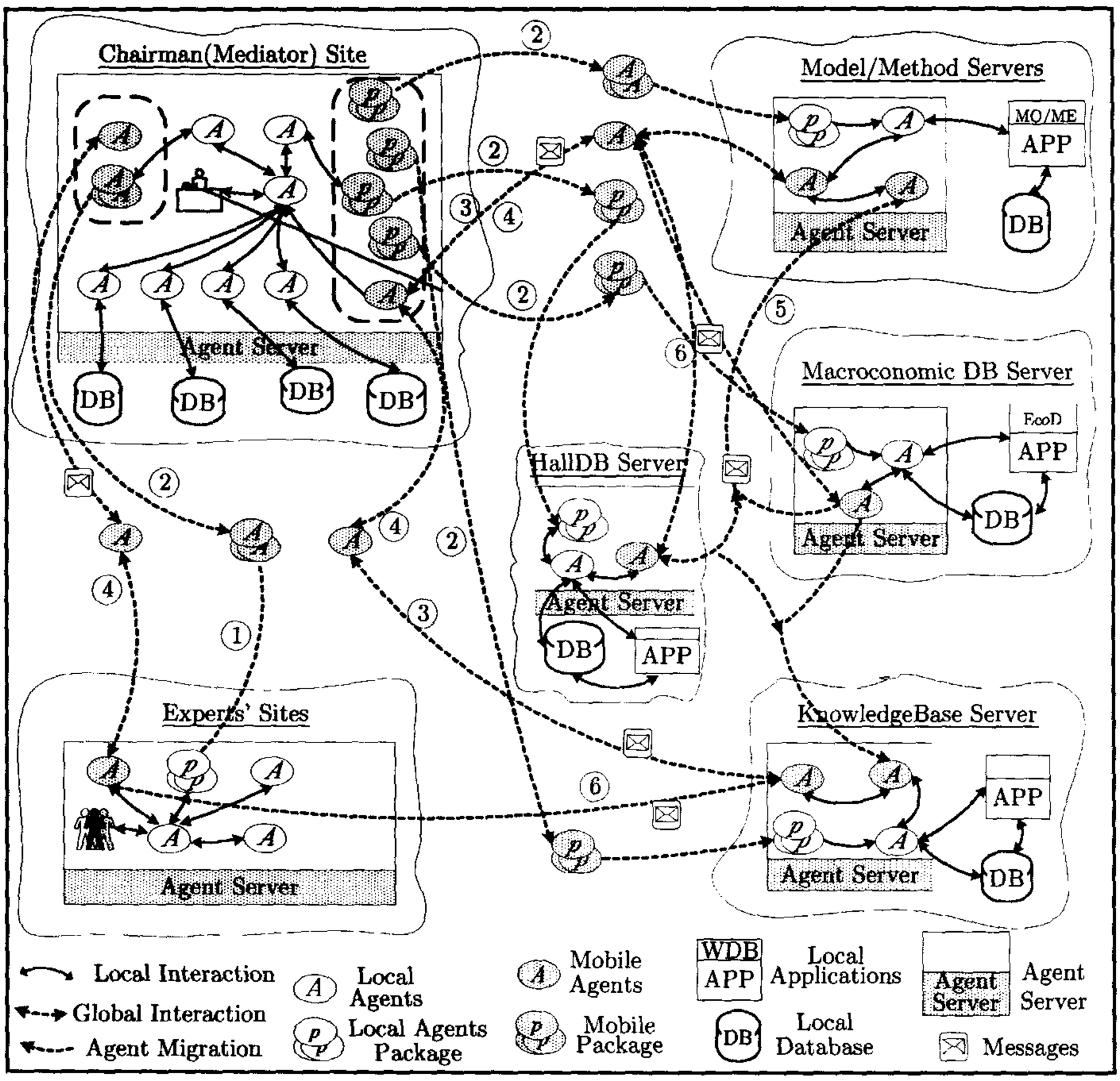

Fig. 5 Framework of Multi-Agent-based HWME

located at an Intranet. The following classes of IIAgents are dwelled in the hall space.

1) Role Agent: This is a Java-based extension of Aglet[1] 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. 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.

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 declares startup of discussion and

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

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 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.

To demonstrate the proposed framework and the workflow of the IIAgent-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 four kinds of resource service sides in TXT texts, Foxpro, Access 2000, and SQL Server 7, respectively. We programmed Aglet-extended agents, an IBM Tahiti server[11] should be preinstalled 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 IIAgent 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

The science of open complex giant system and its methodology have been proposed for more than ten years. The essence of a Hall for Workshop of Metasynthetic Engineering is a human-computer-cooperated intelligent system. For the tremendous complexity of the theory itself, small practical progress has been made.

The emergence of Internet-related technology and agent-based computing forms the underlying technology foundations for building an HWME. In this paper, an attempt is made towards the implementation of an HWME based on these technology achievements. We propose a layered model and the structure of a network-based HWME. Then, we present a framework of IIAgent-based HWME for macroeconomic decision-support, which is based on a 3-tier client/agent/server-nested Requester-Mediator-Provider computing architecture. For this approach, we try to make full use of the internal advantages of agent technology for human-agent cooperation and distributed computing, and discuss some working mechanisms for exertion of these advantages.

It has been shown that a multi-agent HWME based on some flexible and robust working mechanisms is feasible and effective through our qualitative justification.

Further work is needed to strengthen the proposed approach, by

• identifying analysis and design mechanisms for agent-based open giant intelligent systems

• determining the architecture of large scale distributed agent-based HWME

• defining feasibly and flexibly interactive and learning patterns of agents in HWME

• enhancing the ability of human-agent interaction

• providing statistical performance analysis and comparison of agent-based approach with other approaches, for instance, a component-based HWME.

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基于多智能体的人机协作智能信息系统

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摘　要　综合集成研讨厅理论体系是作为处理开放的复杂巨系统的有关问题而提出的，其实质是一个人机协作的智能信息系统. 本文主要探索研讨厅的实现途径，给出了基于网络的研讨厅的层次模型与系统结构，提出了基于内嵌客户/Agent/服务器的请求器－中介器－供应器模型的多智能体研讨厅的多层分布计算模型，并基于 Java 的智能信息 Agent 技术探讨了支持宏观经济决策的多智能体研讨厅的构架及工作机制. 研究表明，基于 Internet 有关技术与 Agent 计算技术有可能实现研讨厅，并由于 Agent 技术的优势而可能得到较好的系统性能.

关键词　人机协作，智能信息系统，综合集成研讨厅，多智能体技术

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