A Study on the Model of Agent-based Distributed GIS

Yingwei Luo Xiaolin Wang Shengri Cong Ning Zhang Muhua Li Zhuoqun Xu Zhonghui Lu

Department Of Computer Science and Technology
Peking University, Beijing, China, 100871
Tel: 86-10-62754939, Fax: 86-10-62755417
*E-mail: **geoagent@263.net***

ABSTRACT Agent technology provides a new method for understanding the features of distributed system and solving distributed application problems. In this paper, after discussing the features and the problems of distributed GIS, we present a model of agent-based distributed GIS——Geo-Agents on the basis of the distributed object components. In this model, we firstly analyze the classifications, features and structure of GIS Agent; there are three types of GIS Agent: system management Agent, general Agent and GIS special Agent, every GIS Agent is a synthetic entity which is consisting of control system, function interface, communicating system, human-computer interface and data resource, and every GIS Agent is autonomous, interactive, initiative, independent and determinate. Secondly, we use message mechanism to provide communication and coordination between GIS Agents, and design a set of Geo-Agents message types according to the properties of GIS and Agent. Lastly, we propose the architecture and network distributed mode for Geo-Agents, and design a task-oriented, personalized script language——GeoScript based on agent for the user. In the mean time, we bring forth a network-based, hierarchical spatial metadata Database frame, which guarantees GIS Agent's capabilities. Geo-Agents not only has the general features of distributed GIS, but also can easily provide the intelligent information services for distributed spatial data, including decentralized-peer computing overpassing the Client/Server structure and cooperation in GIS application. Geo-Agents is a brand-new distributed GIS model and will have a bright future.

KEY WORDS GIS, Agent, Distributed System, Model, Geo-Agents

1. Introduction

Just because of the flying development of Computer Network and Information Highway, the information revolution impels the human society towards information era. After having a great abundance of materials, people have a great demand of information: the proposals such as Global Spatial Data Infrastructure(GSDI), National Spatial Data Infrastructure(NSDI) and Digital Earth(DE), were planed out one by one, all of those proposals will drive the GIS pursuers to focus on the research on distributed GIS.

Currently, the research on distributed GIS is getting afoot, and the productions of distributed GIS are immature and dissatisfactory. The research on distributed GIS is facing on many problems and challenges:

1) The use of the data sources on the network

There are too many spatial information on the network since the internet came to use, a common GIS user has too many difficulties to treat this situation. On the one hand, GIS users do not know how to accurately express their requests for the spatial information their need on the network, how to accurately and effectively locate the resources; on the other hand, the providers of spatial information are short of effective methods to provide their spatial information to the proper users on time. The index and catalog technology now used can not match those needs.

2) Multi data resources

In spatial decision support, the spatial information needed for a map operation or a spatial analysis may be distributed in many spatial data resources, the data management, data access and the data authorities are very difficult to process. This is one of the most important problems of distributed GIS.

3) Distributed computing

The productions of distributed GIS in existence all have a simple point to point Client/Server architec-ture, or a multi-layer Client/Server architecture, the roles of Client and Server are all determinate. Almost all the computing runs on the Server or only a little on the Client. The service provider is relatively concentrated and this computing mode is not a real distributed computing mode.

4) The capability of cooperation

A GIS application always needs the cooperation among several related departments. For example, in the field of urban pipe lines, there are many types of pipe line including traffic line, service pipe, waste pipe, gas pipe, flue, culvert and communication net. All of those pipe lines are charged by different department, but those pipe lines are in the same spatial scope and have correlativity. If any department wants to plan and manage its pipe lines, it must cooperate with other departments. But in the network environment, the current GIS technologies can not fulfill this demand.

Agent technology is derived from distributed artificial intelligence(DAI), but with the development of agent technology, it can be used not only in distributed artificial intelligence, but also in every aspect of computer software, especially in distributed computing based on network[Shi Zhongzhi, Wang Wenjie & Tian Qijia, 1998][Tao Xianping, Lu Jian, etc, 1999]. On the one hand, agent technology provides an effective method to solve the new distributed application problems; on the other hand, Agent technology provides a new reasonable concept model to study distributed computer system more accurately and more roundly[Wang Huaimin, Wu Quanyuan, etc, 1999].
Agent technology provides a new train of thought to process distributed computing and problem-solving. Agent is autonomous, interactive, initiative and reactive, it can not only work on itself, but also impact the environment, receive the feedback information from the environment and readjust its behavior; at the same time, one agent can cooperate with other agents. Agent system releases the restricts of concentricity, non-openness and sequence controlling, provides distributed controlling, dynamic emergency processing and parallel processing. Agent technology can reduce the cost of software or hardware, provide a rapid problem-solving method[Hyacinth S.Nwana] [M.Genesereth & S.Ketchpel，1994][Michael Wooldridge & Nicholas R.Jennings，1994].

This paper attempts to explore a new method to construct distributed GIS based on agent technology, develop an agent-based distributed GIS——Geo-Agents, and explore approaches to solve various problems in distributed GIS.

2. The Concept Model 0f Geo-Agents

Taking account of Agent technology and distributed GIS, we can describe the concept model of Geo-Agents from three aspects: the classifications of GIS Agent, the structure of GIS Agent and the features of GIS Agent.

2.1.The Classifications of Gis Agent

GIS Agent can be divided into three types in Geo-Agents:
1) System management agent
System management agent mainly takes responsibility for global management and coordination.
2) General agent
General agent has some intelligences, it can interact with users and accomplish the users' tasks. General agent receives the users' spatial analysis and query task, disassembles the task, hands them to GIS special agent to carry out through the communication model among GIS Agents, uses the results of GIS special agent to accomplish the task, and returns the final result.
3) GIS special agent
GIS special agent encapsulates the spatial analysis and query in distributed GIS. It can respond the requests of outside, carry out specific spatial analysis and query which can have different data requests, use the communication model to return the result.

Additionally, there is a GuServer which accesses the spatial information, and can be treated as a specific agent. GuServer manages the spatial data and spatial metadata stored in database.

2.2.The Structure of Gis Agent

GIS Agent is consisting of five units(see Fig.1), it is a reactive agent, which can not only carry out its own task independently, but also communicate with other agents, exchange information and cooperate with others.

1)Control subsystem: this unit is the heart and center of GIS Agent. It manages other units, controls and coordinates the whole GIS Agent to work right. It can use the inner data resources and messages received to process spatial reasoning, determine to adopt which function module or component and which running mode to accomplish the relevant task.

2)Functional subsystem: this unit includes function modules, GIS components and other components which can accomplish the agent's function.

3) Communication interface: this unit is the interface to communicate with other GIS Agents. It is in charge of transferring request, control information and exchanging data. The communica-tion among GIS Agents is accomplished through message mechanism(see section 3).

4) Human-computer interface: this unit is used to interact with human, including the leading of GeoScript, the display of spatial data and other interactive operations. Not every GIS Agent needs this unit.

5) Data resource: GIS Agent has two types of data resource——private data and virtual data links. Private data is the fountainhead of management, decision support and coordination, including the environmental description, status description, spatial metadata entrance description, GeoScript statements and rules; Virtual data links include the spatial data that the agent needs to accomplish its

task and the result data. Because of the distribution and quantity of spatial information, every GIS Agent can not be possessed of its own spatial information: on the one hand, it will exhaust too many system

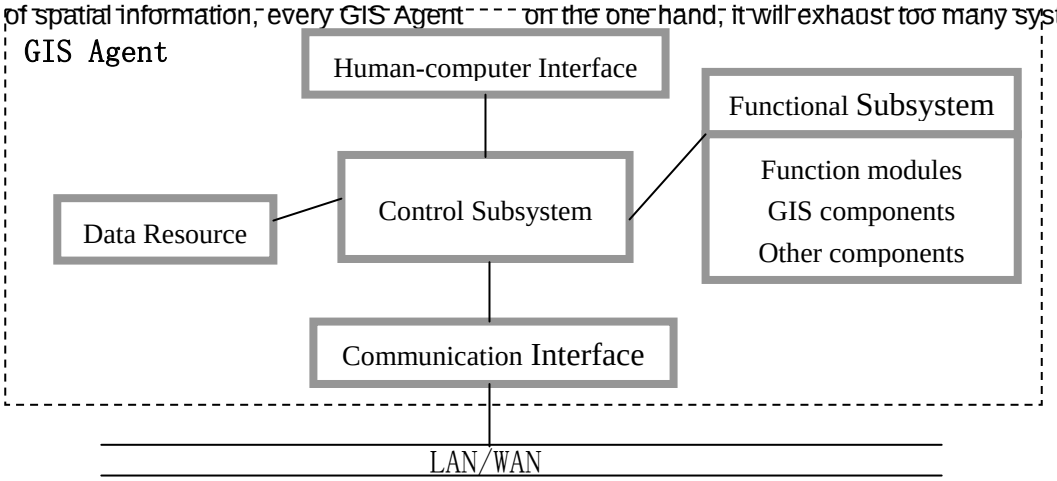

Fig.1 The Structure of GIS Agent

resources; on the other hand, it is difficult to maintain the consistency among the spatial information. So we provide a specific GIS Agent in Geo-Agents to access spatial information and provide virtual data to other GIS Agent(see section 4.3).

2.3.The Features of Gis Agent

In Geo-Agents, GIS Agent is an object class, every active agent is an agent instance(in this paper, the concept 'GIS Agent' is an agent class, not an agent instance). GIS Agent has an interpreter, which can receive and execute GeoScript statements, accomplish specific GIS task through communicating, and cooperating with other GIS Agent. GIS Agent can work persistently, and has the following features:

1) Independence

GIS Agent is an entity which has definite boundary and can be independently invoked in distributed GIS, it encourages to encapsulate data, procedures and communication facilities.

2) Determinacy

Every GIS Agent has its own determinate goals: its capabilities are confirmed, the formats of input parameters and output results are permanent and every agent can comply with some rules.

3) Autonomy

GIS Agent has inner controlling mechanism and inner computing resource. It can decide its behavior according to its status and environmental information perceived without direct control of outside. For example, when a GIS Agent finds that the computing resource it needed is not available at local, it can use some algorithm, request other GIS Agent to get the resource, or hand this task to other agent which can accesses the resource more easily.

4) Interactivity

GIS Agent can interact with human through human-computer interface or GeoScript language. A GIS user can use GeoScript language to describe a task or a rule and hand it to GIS Agent, at the same time, GIS Agent can interact with other agents through message communication, cooperate with other agents. For example, a data searching agent can inquire other data searching agents' information to obtain the distribution of spatial information in the system.

5) Initiative

GIS Agent can keep its promises and work on its own towards its goal, that is to say that a GIS Agent can complete a task itself and then return the result to the user.

3. The Communication Model of Geo-Agents

In Geo-Agents, the communication among GIS Agent is achieved by message mechanism and we adopt two types of message communication here: point to point mode and multi-cast mode.

Every message is a six-tuple<From, To, msgType, replyWith, replyTo, msgContent>:

From	the message sender
To	the message receiver, the receiver can be one GIS Agent or a group of GIS Agents
msgType	message type
replyWith	when this item is not null, it means that the receiver of this message needs to reply this message, and the replyTo of the reply message must equals to this replyWith
replyTo	if this item is not null, it means this message is the reply message of last receive message whose replyWith equals to this replyTo

msgContent	the content of the message, the meanings of the content must be interpreted according to the message type and the conventions between the communicators

The type and content of message are related to GIS and agent technology. We designed almost thirty types of message and their contents according to agent's functions and the requirements of GIS, including CREATE_AGENT, FIND_AGENT, START_AGENT, AGENT_PARAMETER, STOP_AGENT, AGENT_SUCCESS, AGENT_FAIL and so on. Those messages satisfy the requirements of communication among GIS Agents in Geo-Agents[Luo Yingwei, 1999]. Those messages can also be divided into three kinds, and can be translated to communication primitives of other agent communication language(ACL) such as KQML[FIPA 97 Specification]:

1) Request Message: a message which needs the receiver to reply

2) Reply Message: corresponding to request message, it is a reply to the request message

3) Inform Message: a message which is sent on one's own initiative, it is a knowledge message

4. The Architecture of Geo-Agents

Geo-Agents is consisting of six parts: Application, Facilitator, General agent, GIS special agent, GuServer and spatial data database/metadata Database, the relation among the parts can be described by Fig.2.

4.1.Facilitator

In Geo-Agents, there are many distributed Facilitators and they cooperate with each other to control and coordinate every GIS agent to run correctly. The main functions of Facilitator are:

1) Registering the available agents. When registering an agent, it is needed to advertise the agent's capabilities and the invoking methods of the agent.

2) Searching for practicable agent.

3) Creating agent instance.

4) Managing all active agent instances, including the status and lifecycle of active agent instances.

5) Coordinating the communication among active agent instances.

6) Coordinating the cooperation among active agent instances.

4.2.General Agent

General agent is basic agent in Geo-Agents. It provides a series of accessing interface to Application, which can hand task to general agent through those interfaces. Just like structure query language(SQL) of database, Geo-Agents provides GeoScript language to describe GIS task[Luo Yingwei, 1999]. When solving a practicable problem, the application need only use GeoScript statements to describe the task and hand the statements to general agent, general agent will complete the task autonomously.

GeoScript language is an interpreting language, it provides input and output statement, variable defining statement, agent defining statement, agent controlling statement, cooperation controlling statement, parallel controlling statement, condition statement, code migration controlling statement and so on. The main function of GeoScript language is to describe GIS task through manipulating GIS special agent and controlling the relation among agents.

Every agent's capabilities and features can be conducted from the metaphor of its name, so the remarkable feature of GeoScript language is the personification of its developing tools. The number of agent in Geo-Agents can increase limitlessly, but GeoScript language need not be expanded.

So there is an interpreter for GeoScript language in general agent. General agent interprets and executes GeoScript statements which describe a GIS task. General agent divides the task into subtasks and hands them to GIS special agents, then coordinates those GIS special agents to complete the task.

In order to complete some particular task, a general agent can cooperate with other general agents. In Geo-Agents, general agent can cooperate with other general agents in three modes: direct cooperation, peer group cooperation and charge-tributary group cooperation[Luo Yingwei, 1999].

4.3.GIS Special Agent

In Geo-Agents, GIS special agent is used to perform the specific spatial querying or spatial processing or spatial analyzing task of distributed GIS. According to the features of GIS, GIS special agent can be classified into two types: basic GIS special agent and field-oriented GIS special agent. Basic GIS special agent performs the basic services in GIS, including spatial data search,

network, overlay, buffer, map clip and so on. Field-oriented GIS special agent perform modeled tasks in various fields, those tasks can be constructed by a model and can be used generally in the field. This classification of GIS special agent can increase the reusability of Geo-Agents.

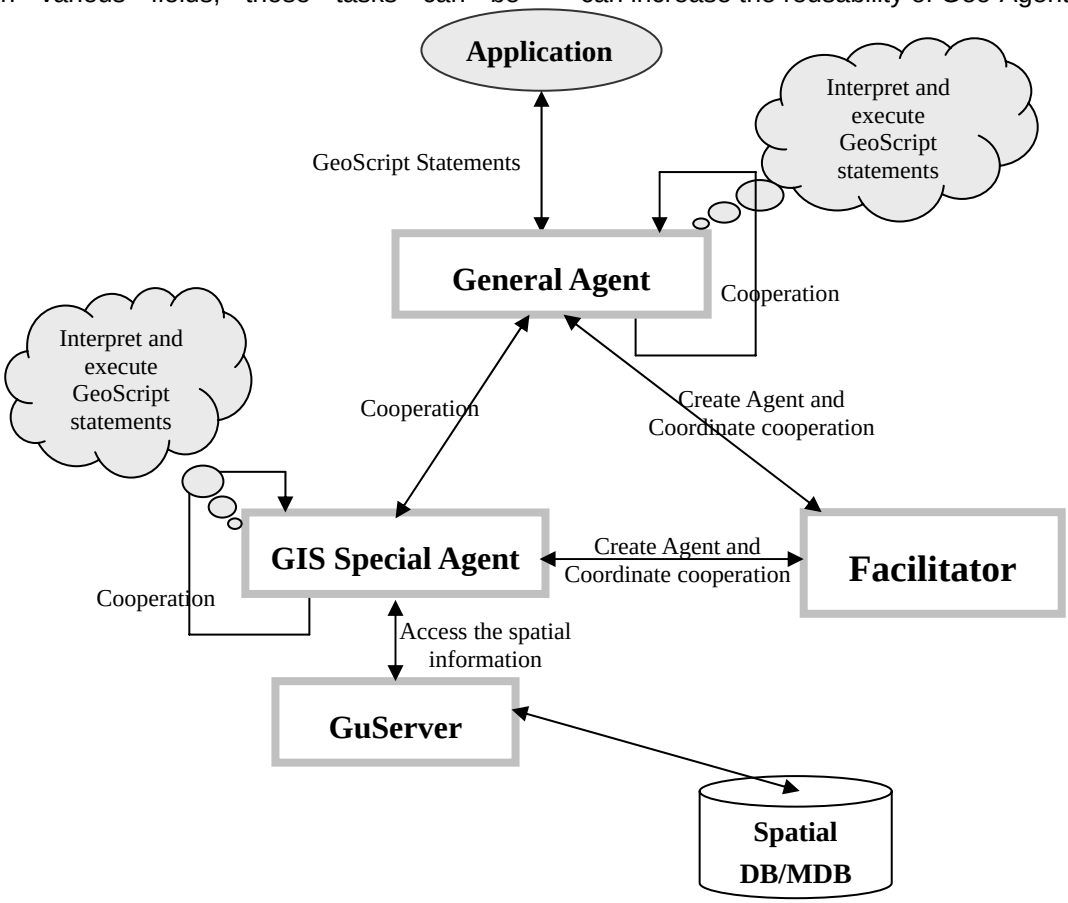

Fig.2 The Architecture of Geo-Agents

Every GIS special agent has definite goal and its capability is confirmed, but a GIS special agent can receive different rules which specify the GIS special agent how to accomplish its task. The rules of a GIS special agent can only be interpreted in its interiority and the formats of rules are determined by the developer of the agent. The rules of different agents are different and the contents of the rules in every agent instance are also different according to the specific task. The number of agent's parameters and rules is varied with the task. The changeability of the rules and the number of rules allows GIS special agent to process different situations of the same task.

Geo-Agents is an agent-based distributed geographical information system, a most important feature of Geo-Agents is the capability of sharing the distributed massive spatial information, so the control on the distributed parallel is an important function of Geo-Agents. Because of the diversity of distribution of spatial information, different requisitions for spatial information in different spatial operations, and different controls on distributed spatial information, the control on the distributed parallel for GIS task is implemented in GIS special agent.

GIS special agent can implement two types of parallel, one is to use several GIS special agents to process distributed spatial information concurrently; the other is to use several GIS special agents to process one massive spatial information concurrently. These two parallel types are different, the first is to use different GIS special agents in different places to process spatial information according to the distribution of spatial information, and it can decrease the transporting quantity of spatial information on the network; the second is to use different GIS special agents in different places to process massive spatial information in one place, and it can decrease the time of processing. Of course, the transporting quantity and the time need to be considered synthetically.

In order to control the distributed computing of GIS task in GIS special agent, we design the GIS

special agent as two levels: task controlling agent(TC Agent) and task performing agent(TP Agent), TP Agent can be of the same type or of different types(see Fig. 3).

When executing a task, if TC Agent knows the distribution of spatial information it needed, it can divide the task into subtasks according to the distribution of spatial information, create different TP

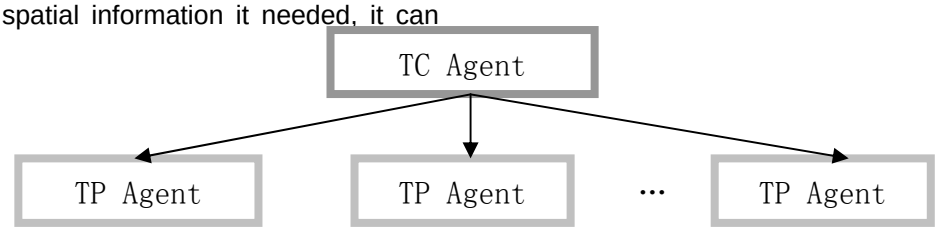

Fig.3 Task Controlling Agent and Task Performing Agent

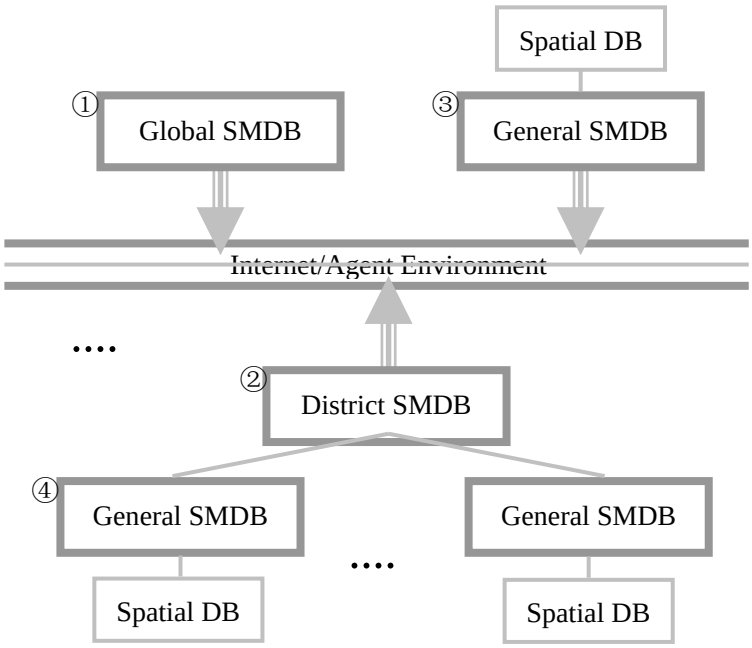

Fig.4 The Frame of Spatial Metadata Data Database

Agents in different places, and hand subtasks to them. TP Agents can execute in parallel or in sequence at the control of TC Agent.

The key problem here is how a GIS special agent know the distribution of spatial information it needed? Spatial metadata is considered, GIS special agent uses the spatial metadata to look for the proper spatial information according to the description of spatial information needed. Because almost every GIS special agent needs to process spatial information, it is impossible and not necessary for every GIS special agent to find the spatial information itself. So we provide data searching agent to look for spatial information for other GIS special agents. When a GIS special agent finds that it can not access spatial information it needed easily, it can communicate with data searching agent, hand the query conditions of spatial information to data searching agent, and then wait the result.

In Geo-Agents, in order to let data searching agent navigate spatial information quickly, we design a network-based, hierarchical spatial metadata Database frame(see Fig.4).The spatial metadata Databases showed in Fig.4 can be divided into three levels: ① is Global Spatial Metadata Database(Global SMDB), ② is District Spatial Metadata Database(District SMDB), ③ and ④ are General Spatial Metadata Database about Spatial Database(General SMDB). ③ and ④ are same in content, but they are in different position in the frame. We regard ①, ② and ③ as independent spatial metadata Database. District SMDB and independent General SMDB can(not

must) be registered in a Global SMDB, but the General SMDB indicated by ④ must be registered in a District SMDB and these General SMDBs registered in the same District SMDB are related. For detail information about this frame, please see [Luo Yingwei, 1999].

General SMDB is an all-sided description about the spatial Database. In Geo-Agents, General SMDB is designed after our spatial data model[Luo Yingwei, 1999] and the Geospatial metadata standard of FGDC[FGDC, 1998].

District SMDB registers all metadata information of General SMDBs in the district and the relations among those General SMDBs.

Global SMDB manages a number of District SMDBs and independent General SMDBs, and all metadata information of those SMDBs(of course include the General SMDBs registered in District SMDB) are registered in it. Global SMDB is the top-level index about spatial information, an user can locate the target data quickly through the Global SMDB.

A data searching agent can connect to several spatial metadata Databases, and find the target data in those meatadata Databases in the mean time. In Geo-Agents, several data searching agents can cooperate with each other to obtain the distribution of spatial information.

5. The Distributed Model of Geo-Agents

We adopt "Agent Region" mode[OMG，1998] to manage the agents distributed on the network in Geo-Agents(see Fig.5).

A "Agent Region" is consisting of one or more hosts, which must be installed with Facilitator(or and other agents). In an "Agent Region", there is one and only one Facilitator which will be configured as AgentServer. Facilitator is used to manage and coordinate agents in one "Agent Region", but AgentServer can manage and coordinate agents among different "Agent Regions" beside the functions of Facilitator(see Fig.6).

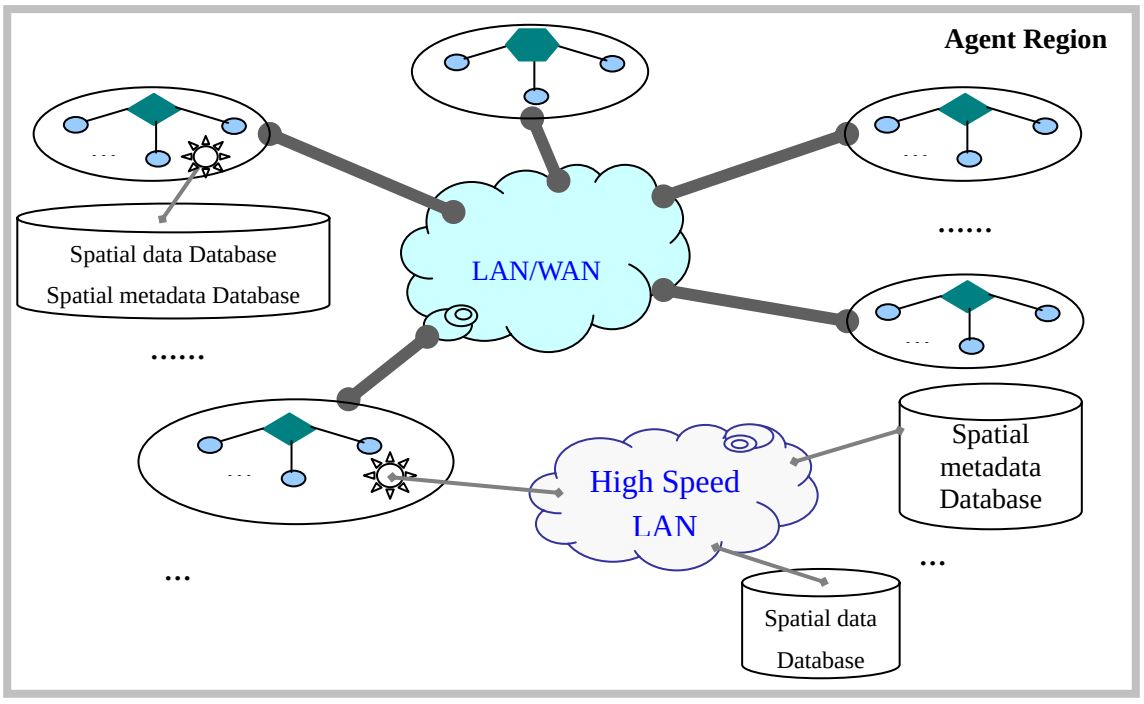

Fig.5 Agent Region

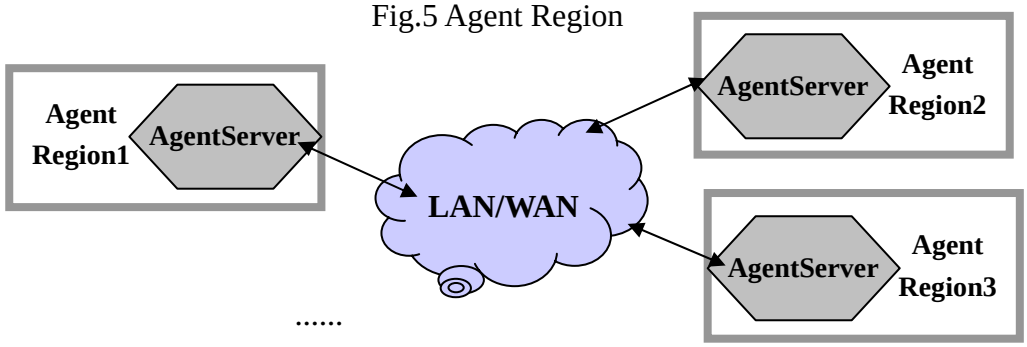

Fig.6 The Relations among "Agent Regions"

A host installed with Facilitator can join an "Agent Region", but if this host wants to perform a function in the "Agent Region", one or more agents must be registered in Facilitator; if an user wants to accomplish a GIS task on this host, general agent must be registered in Facilitator. Every host installed with Facilitator(or and other agents) must belong to only one "Agent Region".

A GIS user can construct one or more "Agent Regions" for the application system according to their needs.

There are two goals to adopt "Agent Region" mode to mange agents distributed on the network, one is to bring the model into clearness; the other is to bring the model into safety. The agent in an "Agent Region" can and only can access other agents in the same "Agent Region" or in other "Agent Region" through AgentServer, and this access is not go-as-you-please, it needs authorization of the target "Agent Region".

6. Conclusion

According to the model described above, we developed a prototype system for Geo-Agents using DCOM technology and multi-thread technology. The consummation and proper running result of this prototype system affirm that Geo-Agents is feasible and has potential superperformance[Luo Yingwei, 1999]. Now, the Model of Geo-Agents and a practical system of Geo-Agents are coming to perfection and implementation.

Today, far-ranging and profound revolutions happened in information field: the new concepts such as Geoscience and Digital Earth come forth, and the new technologies such as internet technology, distributed component object technology and software agent technology are developing and coming to perfection. All these will impulse GIS towards networking, standardization, globalization and popularization. Distributed GIS will serve great function in query, analysis and decision support based-on spatial information. Distributed GIS based on agent technology is possessed of distributed control and intelligence, so it can solve the problems and eliminate the limitations in traditional distributed GIS. With the development of agent technology, more and more GIS researchists will focus on distributed GIS based-on agent technology, and we believe that distributed GIS based-on agent technology will have a bright future in Geoscience, Digital Earth and so on.

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