How Grid enables E-Science?

— Design and implementation of the GEO Grid —

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[Translation from *Synthesiology*, Vol.2, No.1, p.32-41 (2009)]

In this paper, we report on the design and implementation of the GEO (Global Earth Observation) Grid IT infrastructure as an example of E-Science. Using Grid technologies, the GEO Grid provides an IT infrastructure that integrates wide varieties of data sets and computing services for the Earth science community. This paper presents an example of Grid-based E-Science and its application to a wide range of scientific communities. A methodology for system development based on many different software components is also discussed.

Keywords **:** Grid, GEO Grid, E-Science, middleware, software design

1 Introduction

Recently, with the advancement of network technology and the diffusion of network infrastructure, there is active research in E-Science, which is a research methodology enabling science and technology to promote new discoveries and new fields in transdisciplinary research, by using various resources such as high-performance computer connected to high-speed networks, databases, large-scale storage devices, and various kinds of experimental devices. The grid[1] is a technology in which various resources that are connected by high-speed networks are combined safely, actively, and flexibly. It is expected to become the infrastructure technology that supports E-Science. About 10 years have passed since the term “grid” was first used, and the R&D in the elemental technology acquired for the grid has been rapidly progressing. The grid is now in the transition phase from demonstration experiment to practical use.

In addition, there is increased focus on earth observation for environmental issues, including global warming, forecast of and countermeasures for disasters such as earthquakes and floods, and exploration for natural resources. In these fields, it is necessary to conduct data analysis and simulation by referencing various data, including satellite data, sensor data, and geological maps, owned by several different organizations. It is not easy to conduct analysis by sorting through multiple databases while adhering to the different policies of the organizations that own the data. Development of a system that enables this easily has been greatly anticipated. The solution to this problem could certainly be realized using the grid, and therefore, the R&D for the GEO (Global Earth Observation) Grid was set into action.

GEO Grid[2]-[4] is a system and a concept that enables users to handle integrated processing and analysis of geographical information system data as well as various observation data located in distributed environments, by large-scale archiving and high-speed processing of earth observation satellite data using grid technology. Its objective is to provide an environment where research communities and companies can safely and securely use diverse data and make the acquired computation for earth observation. The plan is to promote information integration of geological and satellite information owned by AIST, to promote further integration of this data with a broad range of earth observation information, and also to promote active international cooperation, particularly focusing on advanced use of these resources in Asia. Considering the trend for international standardization, the aim is to maintain international interoperability of all of the information systems and data.

GEO Grid is an example of E-Science. There are many other areas where technological development may be greatly accelerated through E-Science, such as the bio information field for promoting efficient drug discovery using bio information databases, or the medical field for developing next-generation medical diagnosis systems utilizing medical databases and systems to support cancer diagnosis through the use of large-scale medical image databases.

Although most of the basic technologies of the grid have achieved the level of practical use, they have not yet been put to wide use due to the following reasons.

- The grid was originally born in the field of high-performance computation, and is thus seen as “technology for conducting large-scale computation using

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Received original manuscript October 16,2008, Revisions received December 21,2008, Accepted December 21,2008

supercomputers." There are several issues that must be solved for the computation grid, such as: performance issues, since the performance of the Internet relies on "best effort" and there is no actual guarantee for performance; the current parallel programming method is not suitable for grid use due to problems of fault tolerance and simultaneous securing of computers; and technological issues where the scheduling technology for selecting optimal computing resources is only in the research phase.

● There are very few case study reports that can say, "we were able to do this using the grid," and the application community's views are, "we would like to use it but don't know how," "it won't work anyways," or "I have gotten no idea what to use it for."

Not all the basic technologies required for the grid have achieved a practical level, but it is possible to provide novel and realistic research methodologies for various science and technology fields by combining the technologies that have been developed so far. The objective of our research is to build an E-Science infrastructure using the grid as the basis of the GEO Grid, and thus to provide a research environment for earth science researchers, as well as to clarify and solve issues standing in the way of full realization of use of the grid in wide-ranging science and technology fields. The aim is to contribute to the creation of innovations in science and technology fields. To achieve this goal, the required specifications for an information infrastructure based on the scenarios of the case studies of GEO Grid were analyzed, and the system was designed and implemented. The strategy taken was to actually build a system for distributing satellite data to provide a research environment to earth science researchers using the grid. Issues were identified as they arose from the findings and feedback of this implementation, and a strategy for realization was planned.

In this paper, the tasks undertaken to achieve system construction, the security issues in E-Science, and the problems that still need to be solved will be explained using the GEO Grid as an example. The main objective of this paper is, for researchers in application fields, to promote diffusion of the grid by demonstrating the feasibility of the case study, and to enhance understanding of the grid by clarifying "what can be done and what cannot be done." Also, for researchers in IT fields, I will explain the methodology used for constructing a system by combining multiple software components.

GEO Grid is composed of applications, content, and an information infrastructure, and this paper will report on the design and implementation of the information infrastructure. First, the methodology of system construction in the IT field will be discussed. Then, the requirements of the GEO Grid information infrastructure and a design policy based on these requirements will be presented, and finally I will explain the implementation method as well as the findings and results obtained through the construction of the actual system.

2 Requirements of the information infrastructure

The requirements of the GEO Grid information infrastructure are summarized as follows.

(1) Provision of large-scale data
Satellite observation data accumulates to several hundred terabytes to petabytes in size throughout its operation period, and high scalability that enables a quick search for the data needed by the user from such large-scale data is required.

(2) Handling of diverse data
The ability to handle diverse data stored in diverse formats provided by diverse organizations is required, including climate data obtained for different physical quantities, and different time-space resolutions for temperature, humidity, and cloud cover.

(3) Observation of data provision policy
While there are free data sets with no limitation on use, in general, the data owner has the right to license, as well as the right to set and change the conditions, such as authorized range of data access or data format, under which such data can be provided. Thus, it is necessary to achieve flexible access control based on the disclosure policy of the data owner.

(4) Integration of data and computation
It is necessary to provide integration of computation and data, such as large-scale simulation of areas affected by pyroclastic flow based on data, and easily done computations, such as format change, and preliminary processing of data.

(5) Support for a diverse community
It is necessary to set up a mechanism that allows sharing data, computation, tools, and process flow in the form of templates that can be altered flexibly to support diverse communities and various earth science projects, such as environmental watch, disaster watch, and resource exploration.

(6) Ease-of-use
It is necessary to provide tools and interfaces that can be "easily used" by all participants, including users, data providers, and project administrators. Also, the system must allow easy management of tens of thousands of users.

3 Design

Based on the requirements mentioned in the previous chapter, the basic design policy and the usage model were decided before the selection and implementation of specific basic technology. In this chapter, I will explain the design policy and the usage model of the GEO Grid information infrastructure.

3.1 Design policy

In order to share and integrate diverse data and computations as mentioned in Requirement (2), and as described in Requirements (3), (4), and (5), and to provide the results to the research community, the concept of a virtual organization (VO)[5], where the provided data and computations are abstracted as a "service" provided through standard protocols and interfaces, and the usage environment is built by actively combining such services, will be introduced in the design of GEO Grid information infrastructure. A VO is a research environment composed of ideal information infrastructures achieved by combining the services needed by the research community from among the diverse data service and computation services available.

3.2 Usage model

As shown in Fig. 1, there are four roles in the GEO Grid information infrastructure, including service provider, VO administrator, end user, and GEO Grid administrator. The service provider is the owner of data and computation, and provides them as a service to the end user. The VO administrator can be considered the administrator of a community and a project, and engages in construction of the VO, management of users that participate in the VO, and construction of a user portal. The GEO Grid administrator manages the registry where the available services are registered, and manages access control for that registry. The end user basically participates in one or more VOs, and conducts research and surveys by using the services offered.

The service provider registers the information on the services provided in the registry managed by the GEO Grid administrator. The VO administrator searches for the data and computation resources available in the registry, and if there is a service that he/she wishes to use, the administrator negotiates individually with the provider. When the service provider authorizes the provision of service to the VO, the service provider changes the appropriate system setting to allow access to the VO. As mentioned earlier, access control can be set by each VO, each user, or by free access, based on the policy of the service provider.

4 Selection and implementation of the basic technology

Based on the design policy described in the previous chapter, the GEO Grid information infrastructure was implemented using grid technology. Considering the fact that the service must be linked among several organizations, implementation of security in accordance to a standard is mandatory. Also, it is important to effectively utilize the existing tools and software to reduce the cost of implementation and to increase interoperability of the systems. In this chapter, I will explain the selection of the basic technologies and their combination for the implementation of the GEO Grid information infrastructure.

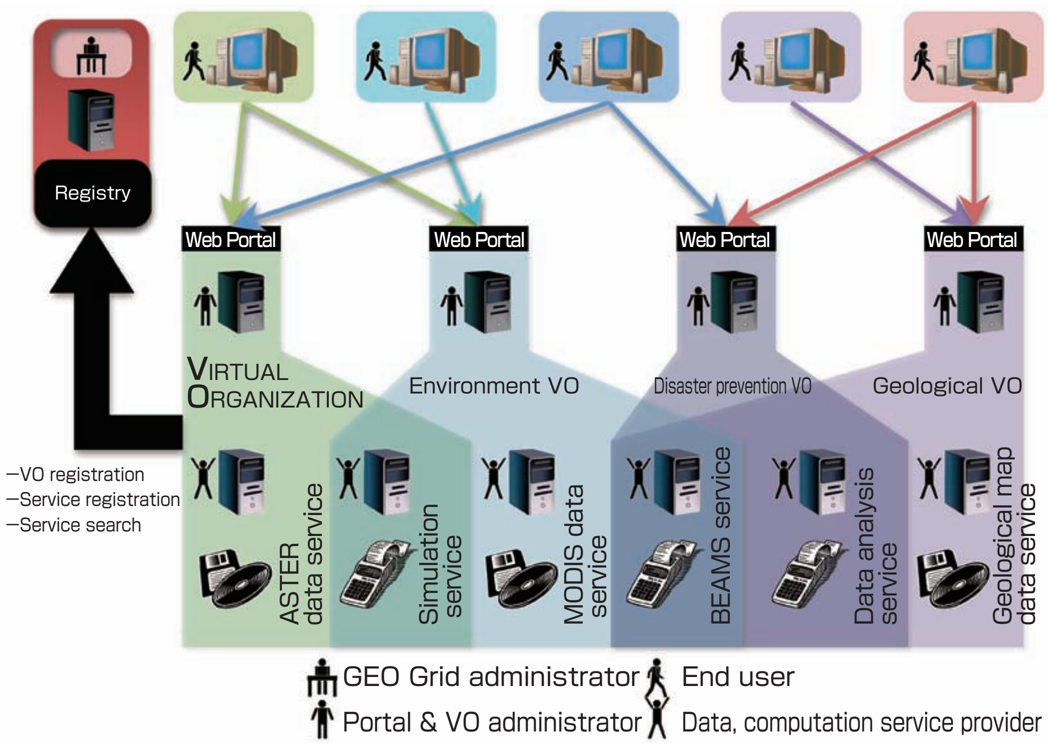

Fig. 1 Usage model of the GEO Grid infrastructure

4.1 Security

The security for the GEO Grid is based on the Grid Security Infrastructure (GSI)[6] and an authorization mechanism at VO level. GSI is a standard authorization infrastructure using the Public Key Infrastructure (PKI) and an X.509 certificate[7], and allows single sign-on and authority transfer through the proxy certificate. GSI is a standard technology for grid security, and considering its compatibility with other systems, and the fact that many grid middleware suits already support GSI, the decision was made to employ GSI for security.

For composition of the virtual organization and access control based on a VO, we used the Virtual Organization Membership Service (VOMS)[8]. VOMS is software developed by the Enabling Grid for E-Science in Europe (EGEE), and it manages the members participating in a VO, as well as member registration, formation of groups, and assignment of roles to users. Also, it issues a VOMS proxy certificate, which is the VO user's proxy certificate embedded with attribute information (name of VO, group name, assigned role, etc.) upon a request by the user. The service provider can adjust various access controls according to its own policy.

The authorized user is normally mapped to the UNIX account at the service provider side, and access control is managed by the authority of the UNIX account. However, in this method, all user entries must be managed by the service provider, and this may increase the management cost for the service provider, and it is not scalable to the number of users. Therefore, an authorization mechanism at VO level is introduced to achieve flexible access control to reduce the burden on the service provider and to allow scalability for the number of users, through authorization at the VO, or group to which the user belongs in the VO, or through approval according to authorization already given.

Other than VOMS, PERMIS[9] and CAS[10] were also available as middleware that provides access control at VOM level, but VOMS was employed for the following reasons: the implementation where attribute information is embedded in the proxy certificate is compatible with the account management system that will be explained in section 4.5; there are several tools included, such as an interface for user management, and high quality software can be expected since it is more widely diffused, compared to other systems.

4.2 Service provision of data and computation resources

To abstract and provide the data and computations as a usable service via standard protocols, middleware that wraps the data and computations, and provides them as a service is used. For servicing data, OGSA-DAI (Open Grid Service Architecture - Data Access Integration)[11] that was developed by the UK-eScience project, and its successor project, the Open Middleware Initiative-UK, is used. For servicing computations, Grid Resource Allocation Administrator (GRAM) of the Globus Toolkit[12], developed by the Globus Alliance of the USA, is used. These are compatible with certification using GSI and VOMS. Other methods for providing computation as a service include implementation as a Java service on Apache Axis, but taking its good compatibility with GSI into consideration, the computation service is provided using GRAM.

Both OGSA-DAI and Globus Toolkit are widely used as grid middleware compatible with GSI, and it is currently thought that there are no other more appropriate choices.

Search results of satellite data and map information are generally provided through web service regulated by the Open Geospatial Consortium (OGC)[13], such as Web Map Service (WMS), Web Feature Service (WFS), or Web Coverage Service (WCS). Software that provides access control using VOMS is available for Apache[14], and is compatible with the security scheme of the GEO Grid.

4.3 Heterogeneous database linkage technology

It is possible to provide an abstracted database as a service using OGSA-DAI via appropriate authorization and approval, but that alone will not enable integration of multiple heterogeneous databases. The function needed by the user is one that allows him/her "to conduct batch query and distributed combination for multiple heterogeneous databases," and therefore, Extended OGSA-DAI-DQP (Distributed Query Processing)[15][16], developed by AIST, is used as middleware.

4.4 Large-scale storage system

It is necessary to consider a storage system for storing large-scale data of several hundred terabytes to petabytes. In most current systems, satellite data is stored on tape, but considering the real-time demand of data search, and the decreased price of hard disks in recent years, use of tape devices or a commercial Storage Area Network (SAN) is not appropriate. Therefore, we decided to use a cluster file system that enables large-scale storage by connecting nodes equipped with hard disks of multiple terabyte capacities via a network. Cluster file system is a technology in which multiple distributed disks are provided as a virtual file system. Although both commercial and free software are available, we employed the Grid Data Farm (Gfarm)[17], developed at AIST, to achieve high throughput using parallel IO, and highly reliable performance with flexible replica allocation.

4.5 Account Management

GSI is an authorization technology based on PKI, where users are required to manage a secret key and a user certificate. However, installing special software to obtain the certificate and appropriate management of the secret key are burdens for the user, and the provision of a simple interface was felt necessary. Therefore, we created a mechanism for managing the user's account and certificate on the server side using the GAMA (Grid Account Management Architecture)[18], developed by the San Diego Supercomputer Center. GAMA is software where functions such as a request from a user for opening an account, and login and account administrator functions for user management are provided as a portlet. The user account is managed by the GAMA server, and the GAMA server has functions such as an authorization station to issue certificates to the user. By using GAMA, the user can access the GEO Grid information infrastructure via authorization by user name and password, without obtaining or managing the secret key or certificate by him/herself.

GridSphere[19] is used as a portal for users. GridSphere is a framework for constructing a portal based on JSR168[20], that has been standardized by the Java Community Process as an API for creating small web components called "portlet," used for portal applications. It provides the authorization module needed to create the proxy certificate from the GAMA server and the portlet for the portal administrator. The original GAMA authorization module only obtains the proxy certificate from the GAMA server and does not include an interface with VOMS. Therefore, we modified the GAMA authorization module so the VOMS proxy certificate is created by a query to the VOMS server after the proxy certificate is obtained from the GAMA server.

4.6 Integration of elemental technology

The basic technologies described in this chapter are compatible with all security requirements based on GSI, and in addition to the implementation of the interface for VOMS in the account management system, integration through interfaces provided by each middleware suite is possible. In constructing a large-scale system like the GEO Grid, it is not realistic to develop everything on our own, and it is important to reduce the development cost by actively utilizing available technologies, while maintaining the core competence.

5 Construction of the actual system

Based on the proposed architecture, we implemented a system in which the main target was ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)[21], a collection of satellite data (Fig. 2). This system is composed of a gateway server that provides access to the GEO Grid cluster through GRAM and Grid FTP server, a server to provide metadata and a catalog of ASTER data, a map server to provide image data as WMS, a GIS server to provide high-grade data such as WFS and WCS, and GAMA and VOMS servers that conduct account management. In this system, three VOs for environment, disaster prevention, and information, currently exist, and each is currently in actual operation, where users are actually using them. ASTER consists of sensors loaded on a satellite called Terra, launched by NASA. There are two sensors loaded, and an elevation model of the earth's surface can be calculated from the results of these observations. ASTER data has been stored in a tape library managed by the Earth Remote Sensing Data Analysis Center (ERSDAC) since the launch of Terra, and is provided to users as fee-based data. Since last year, the data has been supplied to AIST, and at AIST, the ASTER data is stored in a cluster file system rather than as a tape library. The cluster (a GEO Grid cluster) used is composed of 36 dual Xeon nodes connected by Gigabit Ethernet, and its capacity is 264 TB, in total. The cluster

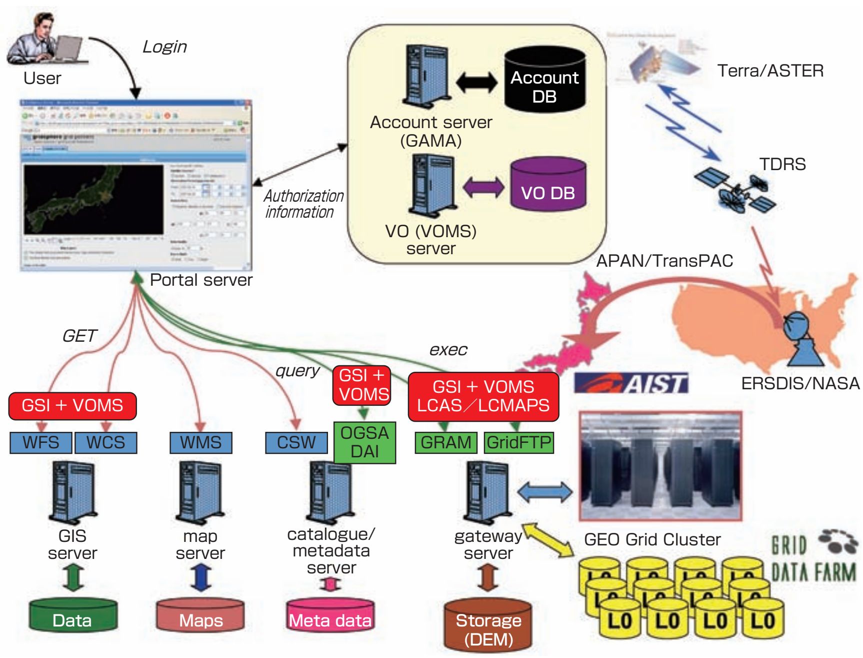

Fig. 2 Architecture of the GEO Grid system

file system used is Gfarm v1.4. At this point, all ASTER data (about 140 TB) is stored, and about 70~100 GB of data are transmitted from NASA daily to be stored in the GEO Grid cluster. For management of metadata, PostGIS, expanded for GIS for PostgreSQL, is used, and the metadata is provided as a data service by OGSA-DAI. For data processing, an F32 cluster composed of 256 nodes of dual Xeon processors connected by Giga-bit Ethernet is used. The GEO Grid cluster and the F32 cluster are connected by a 10 Giga-bit Ethernet.

A demonstration experiment was conducted for the GEO Grid that integrated multiple databases managed by multiple organizations, by constructing a “DB Collaboration Application” that enabled simultaneous search of AIST’s ASTER data, MODIS (Moderate Resolution Imaging Spectroradiometer)[22] data, and Formsat2 data owned by the National Space Organization (NSPO) of Taiwan. It was confirmed that “data search,” “conversion to digital geographic model,” and “transfer of result,” could be implemented as individual services. These were provided as high level services by linkages based on authorization provided by GSI and VOMS, a VO was constructed through integration, and the research environment was then provided to the application community. Also, through applications that allow linkage of ASTER data and free sensor data, and an application that returns the search results in WFS, it was confirmed that the proposed security architecture was able to provide appropriate access control based on the requirements of application and service providers.

6 Discussion

Here, I will discuss the findings obtained through the construction of the system and its subsequent operation.

Through the preliminary assessment of each software component and the development and testing of the ASTER Grid system, we were able to verify the adequacy of both the design and the implementation of the GEO Grid information infrastructure. Using the security framework utilizing GAMA and VOMS, it was confirmed that the system provided an easy-to-use interface to users, and flexible access control in compliance with the policies of the service providers. Also, through access control at the VO level using VOMS, a security system scalable to the number of users could be achieved. By using existing software and tools such as GAMA, VOMS, OGSA-DAI, and the Globus Toolkit, we were able to construct the system with low development costs. Other than the portlet used for applications, the development done by the information infrastructure side was an incorporation of VOMS and GAMA interfaces into the GridSphere. By designing and implementing all basic technologies based on a standard protocol and a standard interface, we were able to easily construct a high-grade system by linking multiple, independent basic technologies. For the construction of an actual grid system, this may require development and use of giant middleware packages such as the data analysis system for the large-scale accelerator experiment in high-energy physics using the gLite Grid Middleware[23] suite developed by EGEE of Europe, or the Cyber Science Infrastructure project where a large-scale research grid has been constructed over university and research institutes using the NAREGI middleware[24] suite developed by the National Research Grid Initiative of Japan. The Earth System Grid[25] and GEON[26] of the USA also intend to construct a research environment with integrated earth observation data as in the GEO Grid. All of these use authorization and approval based on grid security in some part, but most are composed of non-grid technology based on web services. A case like GEO Grid is highly original, where the research environment is constructed with flexible access control based on grid security by creating a VO through the combination of data and computation provided as a service using various grid middleware suites. Therefore, this research is significant because it demonstrated that a large-scale system could be readily built by linking the grid middleware, as long as all elements were implemented according to standard security and protocols, as described in this paper.

Through building this system, it has been confirmed that the basic technologies can be utilized without any significant problems. As issues that must be solved toward full realization, the following five can be pointed out.

(1) Creation of a tool kit
Many of the grid middleware suites used had complex installation and configuration requirements, and cannot be readily installed and used by everyone. Although the user is provided with a simple interface that can be used with only a user name and password, it is necessary to provide a tool kit where the required middleware set can be easily designed and installed for the benefit of all participants, including service providers and VO administrators, in order to promote further development in various application fields.

(2) Realization of a more flexible authorization function
Some of the existing application communities already employ their own authorization function, such as OpenID currently used in some bio information fields. To achieve seamless transfer from the existing research environment to an E-Science environment, it is necessary to implement a more flexible authorization function that produces grid authorization information from the authorization mechanism that is already being used, such as those of OpenID, Shibboleth, or Kerberos.

(3) Construction of workflows
Many of the application researchers use certain preset

procedures (process flows) for a large quantity of data. To obtain required data quickly when conducting multiple simulations, such as in seismic vibration analysis and liquefaction projection during the occurrence of earthquake, or in flood projection as water levels rise, it is desirable to construct a workflow for the procedures. The preceding workflow studies have already been done for the grid, and the introduction and construction of workflows is necessary for the GEO Grid.

(4) High performance processing
Large-scale image data processing requires large-scale computation resource, and existing software may consume several minutes to several tens of minutes for image processing. Considering interactive data transmission, it is desirable that image production takes only a couple of minutes, at most. Recently, multi-core architecture suitable for image processing, like CELL/B.E.TM is beginning to be used, and high speed capacity for image processing and simulation, utilizing the latest architecture, can be expected in the GEO Grid.

(5) Development of a metascheduler
In the system constructed in this research, the computation services for simulation and image processing are provided from a single site. In the future, when the same services are provided from multiple sites, it is necessary to develop a registry that manages where data is located and what kind of services are available, i.e., a monitoring system that checks the usage status of the computation server that provides the system, and a metascheduler that selects "seemingly best" services based on that information.

Research is being done on all five issues, and issues (1) to (3) can be addressed in about one or two years. For issue (4), it is necessary to increase the speed capability of the software, and in many cases, the source program is not provided due to licensing conventions for commercial software. However, preliminary assessments have been conducted for increasing the speed of image processing software on CELL/B.E.TM, and there is a possibility for significant improvement. Issue (5) is the biggest issue for the grid. To realize the concept of the grid – a world "where service can be available without thinking about which resource is used when the computer is connected to the network," a metascheduler function is mandatory. But it is extremely difficult to select the "optimal" resource in a complex environment where the decision of what is "optimal" is based on the characteristics of the computation (such as the ratio of quantities of communication to computation) and where the resources (network and compute server) that compose the grid changes dynamically in structure and efficacy. Research will continue to try to solve this issue by setting a limit on the range of criteria that will not interfere with the user in the scenario of the GEO Grid.

7 How to proceed with subsequent R&D

In this study, the implementation of the system was considered by studying the demands and ideas from the Institute of Geology and Geoinformation, the Geological Survey of Japan, the Research Institute for Environmental Management Technology, and the Grid Technology Research Center (currently, a part of the Information Technology Research Institute), as a transdisciplinary research project of AIST. The Grid Technology Research Center strengthened the organization to help advance the R&D effort for the GEO Grid by shifting personnel from the GSJ to the Center; by employing researchers in application fields of the National Research Institute for Earth Science and Disaster Prevention, the Japan Aerospace Exploration Agency, and the National Institute for Environmental Studies; and by close discussions between the researchers in the information and application fields.

GEO Grid management meetings were held regularly to discuss the policy of the GEO Grid, relationships with external organizations, the clarification of pressing issues and measures, as well as for progress management. To ensure the smooth operation of a large-scale project with total of about 20 people from the application and information fields from the Grid Center alone, the application and information fields regularly held meetings for progress management, to pinpoint problems and to discuss the solutions, and great effort was made to share information on the issues among the research team members. It was important for the researchers of both fields to work at the same location, and to be in an environment where frequent discussions and brain-stormings were possible, other than just at the regular meetings.

For this research, several middleware suites, developed not just by AIST but also by overseas institutions, were used. Basically each middleware suite is implemented through the employment of a standard protocol and interface, but there were some problems due to defective implementation and a lack of function in the middleware when actual tests were conducted. Since there was close collaboration among the developers of each middleware suite through the Open Grid Forum[27], a grid standardization organization, and through international conferences, it was possible to ask the developers to take immediate measures when issues arose. Also, it was possible to have them incorporate new functions in the next version by communicating the required specifications, and they, in turn, provided advice for specific implementation methods. In many cases, a grid system is realized by linking an extremely large number of middleware suites, and it is not practical in terms of development cost to implement everything on our own, and therefore it is important to engage in daily communication with other developers to create a system where R&D can be conducted with cooperation from overseas organizations, while maintaining the core competence.

8 Summary and future issues

This paper reported on the findings obtained through the design, implementation, and actual operation of the GEO Grid information infrastructure. The way of thinking about VOs in E-Science and methods to realize management, authorization, and approval of user accounts were discussed. In the GEO Grid information infrastructure, all computation and data resources are provided as usable services via a standard protocol. The research community forms a VO, and the required services are combined and provided to users within the VO. A security infrastructure that is scalable to the number of users is implemented through approval at VO level, as is flexible access control based on the policy of the service provider, through an authorization mechanism using the VOMS attribute.

The plan is to evaluate and brush up the system through on-going operations while continuing to work on R&D for the issues mentioned in chapter 6. About a year and half had passed since the start of system development of the GEO Grid, and it was possible to construct a system suitable for practical use, surpassing the prototype stage. However, about a two to three year period of R&D is still necessary for the full realization of the system by solving the remaining issues.

Acknowledgements

This research was conducted as the researchers of the application and information fields of the GEO Grid project engaged in active discussions on system requirements and solutions. I thank all the researchers who participated in the GEO Grid project. I received advice on OGSA-DAI from Dr. Neil Chue Hong of the UK E-Science Centre and Dr. Valerio Venturi of OMII Europe. I had useful discussions on OGSA-DQP with Dr. Steven Lynden of AIST. Also, I received various advice on VOMS, LCAS/LCMAPS, and Gridsite from Dr. David Groep of the Dutch National Institute for Nuclear and High Energy Physics. I am grateful for their contributions.

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Discussion with Reviewers

1 Readers of the paper

Question and comment (Kazuhito Ohmaki)

I think the objective of the paper, or who (what kind of people) you wish would read the paper, is unclear. Do you wish to say, "This is an age where the world is full of software with excellent function rolling around like PDS, and if we pick them up and combine them, we can make incredible things, and fairly high performance can be obtained by presenting core competence?" And then, do you want to present grid technology as an example to a wide range of software engineers to give them assurance, or do you want to say that although the application is now for geology, the range must widen to astronomy and the environment? Or do you want to emphasize that it is an age where software or data should be presented as a "service?" Or is it all of the above? I think you should explain the objectives more clearly with more words in the "introduction" or the "discussion" and "conclusion" sections.

Answer (Yoshio Tanaka)

The main purpose of this paper is to contribute to the creation of innovation in science and technology by promoting the diffusion of grid technology and E-Science infrastructure by using that technology, and to demonstrate the construction of an E-Science infrastructure using grid technology, with GEO Grid as an example, and finally, to make all of this available to researchers in wide-ranging fields of science and technology. Also, I wish to show that a large-scale system can be realized easily if the basic technologies are implemented according to standard protocols and APIs. I wish to emphasize the importance of standardization and collaboration with overseas institutions in developing each basic technology. I also wish to point out that in constructing a large-scale system, it is not realistic to development everything on your own, and it is important to reduce the development cost by actively using available technology, while maintaining the core competence.

I added some explanation in chapter 1 to clarify these themes. I also modified the abstract.

2 "Distributed computing"

Question and comment (Kazuhito Ohmaki)

Although I think the idea of grid technology for connecting high-speed computers is important and interesting, from a layman's point of view, I don't feel that the concept of grid has become any more familiar than it was 10 years ago, when it was first proposed. Or, do you think it is correct to say, "No, that is a lack of knowledge on the past of the reviewer, and it's totally different from what it was before, and it is now within reach?"

Answer (Yoshio Tanaka)

While many of the basic technologies of the grid are maturing, I think the reason it does not feel quite familiar is because there are some outstanding technological issues, particularly in the computation grid, and there are very few case studies or success stories using the grid. However, the grid is at the level where it can accomplish a lot with currently available technologies, and in fact, the GEO Grid is capable of responding to the demands of the earth science researchers by combining current technologies. I added this point to chapter 1. The objective of this study, as mentioned in the Answer for Discussion 1, conforms to this explanation.

3 Security

Question and comment (Kazuhito Ohmaki)

I think the issue of security is always a problem, whether past or present, in the VO concept. Is that the only remaining issue, and if this is solved will it become sort of operational? Or, is there some other factor? Or will it be solved if a *de jure* standard is employed? I would like to see some mention of the "issues," particularly those pertaining to grid technology.

Answer (Yoshio Tanaka)

For security, I think the technology that can be put to practical operation is already established for most science and technology fields. I think there are three factors or problems in grid technology: many of the grid middleware suite cannot be easily installed or set. They are not user friendly in terms of important issues such as handling of user certificates, etc. And the key technology, a metascheduler, is still in the research phase. Detailed explanations of these problems were added to "Issues to be solved" in chapter 6.

4 Strategy and scenario

Question and comment (Naoto Kobayashi)

GEO Grid, as an application of grid technology, is an extremely effective technology that may help solve many issues of the 21st century, where society must become sustainable through prevention of global warming, resource conservation, disaster projection and prevention, and efficient land use.

Based on the above viewpoint, the papers of *Synthesiology* emphasize the relationship of the research objective and society, as well as the importance of this scenario. In this paper, I see the greater objective concept, but I think the specific research objective is unclear. I understand ultimately that the essence of the grid technology is for everyone to be able to conduct information processing freely, utilizing CPU resources and databases that are distributed in several different places, as if they exist in one's own computer or in the close proximity, without being conscious of the existence of the grid technology. If that is true, I think you should have an explanation of what is the final objective of the GEO Grid in this research project, and to what phase you wanted to attain in this paper amongst the greater objectives. I expect also to see some explanation of the strategy and scenario for that purpose.

Answer (Yoshio Tanaka)

As you pointed out, the final objective of the GEO Grid and the current level of achievement were not clear, so I added the final goal in chapter 1, as follows: "The objective of this research is to build an E-Science infrastructure using the grid as the basis of the GEO Grid, to provide a research environment for earth science researchers, and to clarify and to solve the issues in the way of a full realization of its potential in wide-ranging science and technology fields. The aim is thus to contribute to the creation of innovation in the science and technology fields."

Also, I explained the issues that need to be solved that became clear in the process of system construction in chapter 6, and added some further explanation in chapter 8. I also added an explanation of the strategy for achievement of the final goal in chapter 1.

5 Synthesis of basic technology and an explanation of technical terms

Question and comment (Naoto Kobayashi)

The individual basic technologies and the reason for their selection are described very understandably. However, there are many technical terms, and they must be explained in the text. On the other hand, the issue is a synthesis of the basic technologies. It is described that basic technology is designed and implemented, based on standard protocols and standard interfaces, but please explain the uniqueness, innovativeness, and superiority of such a synthesis. Of course, the ease of system construction is an advantage having both uniqueness and superiority. I think it would be good if you can address whether the quality of security and service obtained from this synthesis is sufficient from the view point of GEO Grid, or whether it requires more improvement.

Answer (Yoshio Tanaka)

I think the superiority and importance of this research and the main theme of this paper is to show that a large-scale system can be realized easily if the basic technologies are implemented according to standard protocols and APIs, and to state that for the development of each basic technology, standardization and collaboration with overseas institutions are important. And also, that it is not realistic to develop everything on our own when constructing a large-scale system, but it is necessary to reduce the development cost by actively using available technologies while maintaining the core competence. These caveats are mentioned in chapter 6, and I also added some descriptions in chapter 1.