Construction of Japanese Virtual Observatory (JVO)

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(Manuscript received September 8, 2004)

Large amounts of high-quality astronomical data are obtained from the Subaru Telescope and other observatories located throughout the world, and this data is stored in worldwide locations. It is now more important than ever to have an observational database that enables astronomers to search for and collect valuable astronomical data from this vast collection and perform research through statistical analysis. The National Astronomical Observatory of Japan (NAOJ) has therefore started construction of a system called the Japanese Virtual Observatory (JVO) that will connect these observational databases via high-speed networks so they can be used collectively as a single virtual data archive. Fujitsu has been collaborating with the NAOJ to develop JVO prototype systems. To build the JVO, a virtual integrated environment for the distributed data will be required. To achieve this, three issues must be considered: 1) construction of a virtual data storage system, 2) efficient use of the vast amount of distributed data, and 3) the fragileness of the distributed environment. This paper describes and evaluates the JVO prototype constructed using Data Grid technology to ascertain the feasibility of a virtual integrated environment for the distributed data.

1. Introduction

In the field of observational astronomy, astronomers have always attempted to develop new observational instruments and telescopes, extend usable wavelength bands, and improve data analysis methods in order to observe otherwise invisible phenomena. Radio, infrared, and X-ray astronomy have evolved based on the achievements made in optical astronomy, and researches are using these new types of astronomy to learn about the transformation of low/high-temperature interstellar gasses into stars and planets. On the other hand, there are many unsolved mysteries, including the origin of the universe, galaxy formation, causes of the large-scale structure of the universe, and the destiny of the universe.

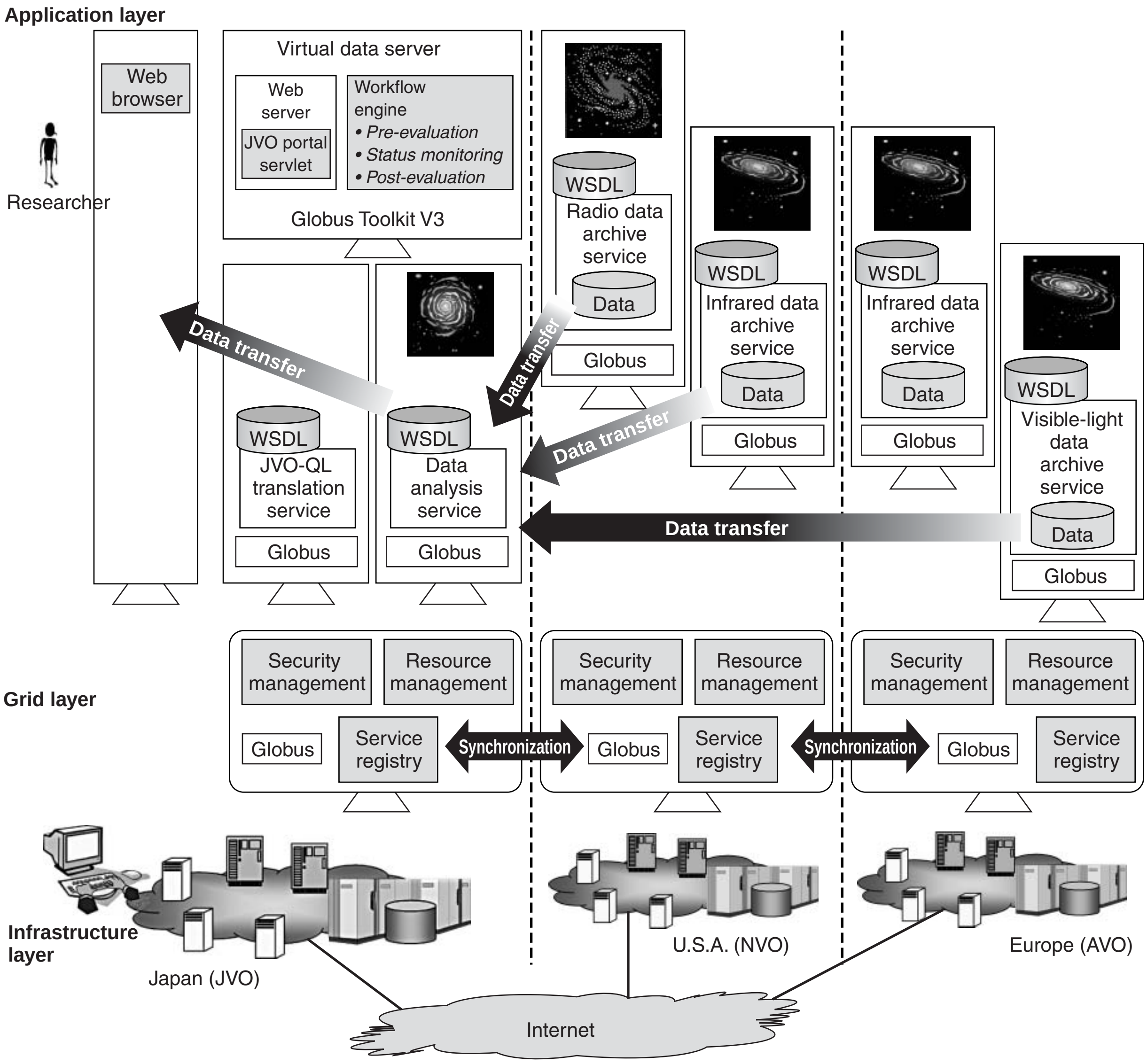
Unveiling these mysteries at the forefront of modern astronomy requires enhancements to the sensitivity and other performance factors of observational instruments. Observational databases play a crucial role in that they enable astronomers to study the statistical behavior of stars based on the physical characteristics of many stars and thereby discover unknown astronomical phenomena. Therefore, astronomical research using observational databases is expected to become the mainstream of astronomy in the 21st century.

Fujitsu has collaborated with the National Astronomical Observatory of Japan (NAOJ) in the development of a prototype of the Japanese Virtual Observatory (JVO), which will be constructed to promote research using observational databases at NAOJ. This paper describes and evaluates this prototype system.

2. Plans for virtual observatories

Data about the universe obtained by ground-based telescopes and various observational instruments mounted on satellites is stored as numerical data in computers around the world. This data collectively represents a virtual universe that can be observed via computer networks. An observatory for observing a virtual universe is called a Virtual Observatory (VO), and virtual observatories are being constructed in Europe, the US, Japan, and other countries. **Figure 1** shows some example plans for virtual observatories. The figure shows, from left to right, the Japanese Virtual Observatory (JVO) in Japan, the National Virtual Observatory (NVO) in the US, and the Astrophysical Virtual Observatory (AVO) in Europe.[1)-3)] An interface to connect virtual observatories with each other is being studied by an organization called the International Virtual Observatory Alliance (IVOA).[4)]

Construction of virtual observatories has become realistic thanks to the development of



WSDL: Web Service Description Language

Figure 1
Future plan for virtual observatories.

computer environments. CPU performance has made rapid progress, the capacities of hard disk drives and magnetic tape units have increased, and the prices of these instruments have fallen dramatically. The development of the computer environment has enabled us to easily store and analyze a vast amount of data. Also, the Internet has enabled us to easily transfer a vast amount of data because its usable bandwidth and therefore the communication speed have been increased. Now, astronomers can use remote computer resources as if they were local ones.

3. Virtual integrated environment for distributed data

Realizing a virtual observatory requires a virtual integrated environment for distributed data that enables astronomers to securely use the numerical data stored in computers distributed around the world whenever they need it. The virtual integrated environment for distributed data must meet the following requirements:

1) It must be possible to use the distributed data without knowing about the individual computers and data storage systems that manage and store the data,
2) the vast amount of distributed data must be used efficiently, and
3) communication and data access must be performed by taking the fragility of the distributed environment into account.

Regarding requirement 1), the virtual integrated environment needs to act as a single virtual computer system so that users are free from the need to consider the differences in the locations, operating systems, and management systems of the distributed computers to which they connect via the Internet. Furthermore, users must be able to use the environment as if it were a single virtual data server without considering the differences in individual distributed data storage systems and management software (e.g., RDBMSs).

Regarding requirement 2), because the vast amount of data is distributed around the world, the virtual integrated environment must support efficient data access methods that can minimize the data transfer via networks and ensure high throughput.

Finally, regarding requirement 3), the virtual integrated environment must support fault-tolerant communication and data access methods, because operation failures and other troubles may occur in the computers storing the data or on the network paths to the computers.

4. Application of Grid technology

Grid technology is the latest technology for constructing a distributed computing environment using the Internet and is expected to become an infrastructure for large-scale computation and data sharing. The Globus Toolkit is used worldwide as a middleware for constructing a Grid environment in many Grid projects. Next, we describe how Globus Toolkit can be applied to the virtual integrated environment for the distributed data of the virtual observatory in order to meet the requirements described above.

To construct a single virtual computer system to meet requirement 1), a framework of single sign-on authentication provided by the Globus Toolkit is adopted to absorb differences in management systems. Users can safely use the computer resources of the entire virtual integrated environment for distributed data after performing authentication only once.

To efficiently use the vast amount of distributed data in compliance with requirement 2), we adopted the Reliable File Transfer (RFT) service provided by the Globus Toolkit. The RFT service provides a framework for high-speed, third-party transfer of files by striping. Third-party transfer is a mechanism for transferring data between two server computers according to instructions from a client.

Because the Globus Toolkit provides only basic library-level functions at present, some user applications must be developed to comply with requirement 3) to construct the virtual integrated environment for distributed data. The JVO prototype has incorporated architecture that applies the Grid Services provided by the Globus Toolkit version 3 (GT3).

5. Development of the JVO prototype

Figure 2 shows the configuration of the JVO prototype based on the assumed virtual integrated environment for distributed data. The JVO prototype consists of client computers operated by users, a virtual data server, and multiple database servers. Each client computer uses an arbitrary operating system on which a Web browser can operate, and each server computer in this prototype uses Solaris or Linux as the operating system. ORACLE and PostgreSQL, which are often used for astronomical research, were used as the RDBMS to construct the virtual integrated environment for the distributed database. It stores the astronomical data collected by the Subaru Telescope and other observational instruments.

The following describes the main application developments for realizing a virtual integrated environment for distributed data in the JVO prototype.

A single virtual computer system that meets requirement 1) is achieved by constructing a mechanism that enables users to perform all operations on the portal server of the virtual data server. The virtual data server bundles multiple database servers and makes the system look as if there is a single database on a single computer. Users' queries to distributed databases are made using

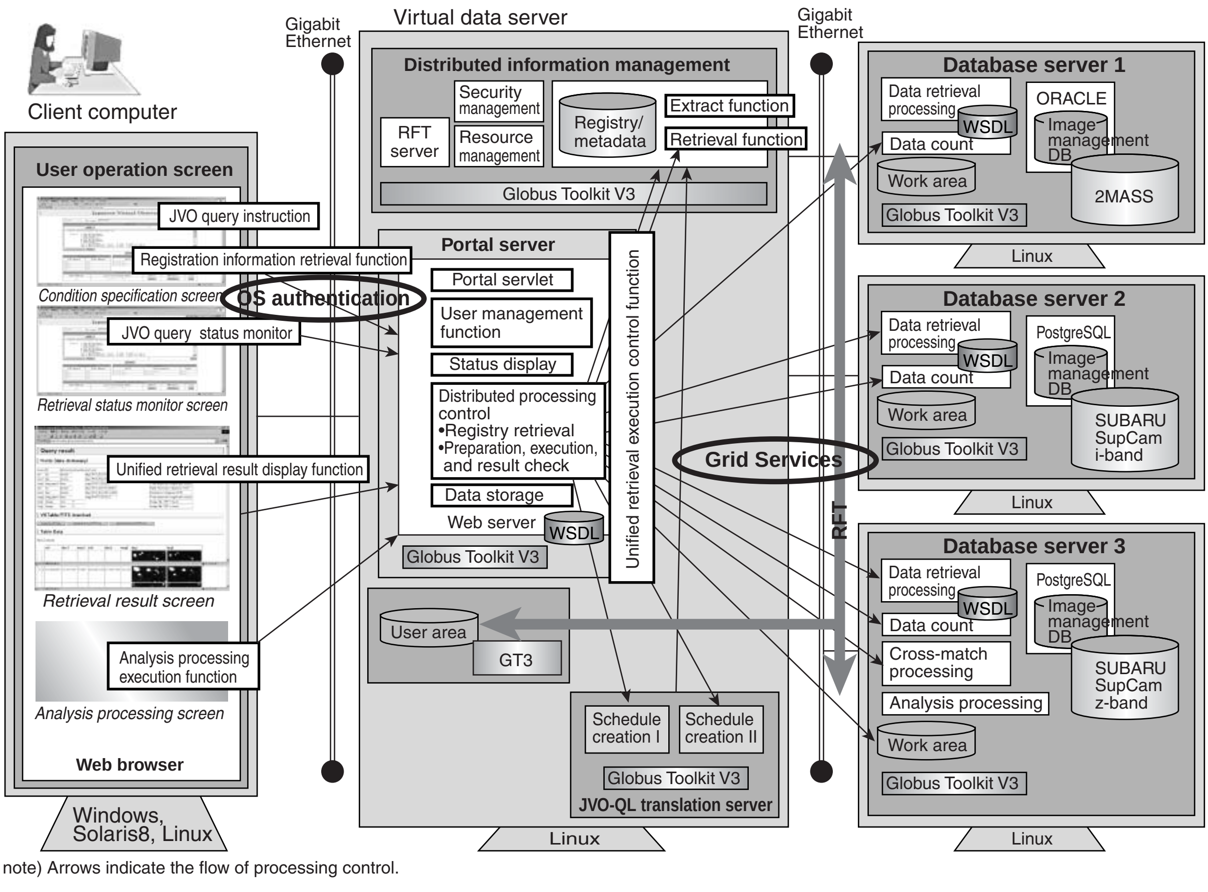


Figure 2
Features of JVO prototype.

the JVO Query Language (JVO-QL), which we defined as an extension of the Structured Query Language (SQL).

The flow of a query operation is as follows. The controller in the portal server requests the JVO-QL translation server to translate the JVO-QL specified by the end user and produce a query execution schedule. Then, the controller performs remote calling of the relevant service located on a database server. The query result is put in the user's area on the virtual data server and referenced by the end user.

Efficient access to the vast amount of distributed data in compliance with requirement 2) is enabled by the use of a two-stage scheduling method that can minimize the data transfer via networks. When data is searched over multiple database servers by an integrated query operation, the scheduling function checks the number of data items returned as the query result from each database server and thereby minimizes the amount of data that needs to be transferred.

Figure 3 shows an example of an integrated query of the data distributed over two database servers: database server A (number of query results: 100) and database server B (number of query results: 10 000). If all data (query results) is collected into the virtual data server, the data to be transferred amounts to 10 100 items (data transferred from servers A and B), as indicated by ①. However, if the number of query results (data items) from each database server is known, it is possible to transfer data from a server with less query results to another server with more results. In this case, database server A has less query results than database server B, so the data to be transferred amounts to only 100 items, as indicated by ③. Thus, the total processing throughput can be improved.

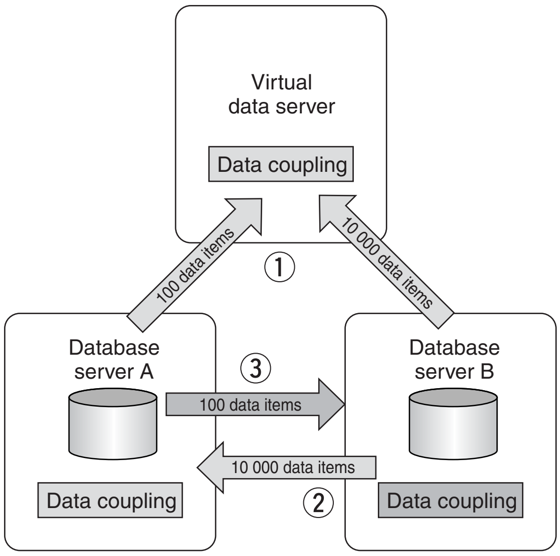


Figure 3
Minimization of data transfer.

To perform communication by taking into account the fragility of the distributed environment in compliance with requirement 3), we developed a framework to automatically access alternative database servers that provide the same data. This framework uses the registry function of the Grid Services to manage the locations of services that provide the same data. A service is called in successive steps such as retrieving the registry, referencing the relevant Web Service Description Language (WSDL), arranging the calling interface, and executing the process on a relevant remote computer. The alternative calling method prepares a list of identical services as candidates cataloged in the registry. Therefore, even if a selected service terminates abnormally, another service is selected from the candidate list and called.

6. Evaluation of the JVO prototype

Next, we describe how the JVO prototype meets the requirements for the virtual integrated environment for distributed data.

Requirement 1) —access without knowing about the individual computers in distributed systems—is met by using the portal server and the single sign-on function of GT3. The portal server enables users to use the distributed computers as a single virtual computer system. The single sign-on function enables users to easily and securely start remote processes on computers under different management systems regardless of their locations. However, there are considerable overheads due to authentication and encryption processing that cannot be ignored in interactive operations. This problem must be studied and solved before the actual JVO system is developed.

Access to the virtual database is also enabled by users' data operations with JVO-QL. For service calling on individual database servers, queries of the registry for the Grid Services and the remote process execution function of GT3 are adopted to enable access without knowing about service locations. The remaining issue is to verify whether the advanced data operations required by astronomers will be supported by the extended JVO-QL.

Requirement 2) —efficient access to the vast amount of distributed data—is met by the application of a scheduling method that minimizes the data transfer via networks. Because this scheduling method examines the number of data items on multiple database servers before data transfer, it is effective only when the time needed for examining the number of data items is shorter than the data transfer time.

Requirement 3) —secure access in consideration of the fragility of the distributed environment— is met by installing a process that prevents abnormal termination of requested processing. The process installed in the JVO prototype is a controller that dynamically determines the target machine for the process from a candidate list. If a service terminates abnormally, an alternative service cataloged in the candidate list is selected and the service is executed automatically. This function enhances the fault tolerance of the JVO. In the future, further study should be done to develop an advanced controller that can take into consideration the operation and load conditions of the other systems and networks linked to the JVO.

7. Conclusion

A prototype of the Japanese Virtual Observatory (JVO) has been developed, and a method to apply the Globus Toolkit, version 3 (GT3) to the prototype and problems as well as restrictions concerning GT3 application were studied. Various functions for applications were also developed and installed, and the prototype was evaluated to see how well it met the requirements for realizing a virtual integrated environment for distributed data. The prototype system can be applied to virtual integrated systems in other fields of science, intra-company systems, and inter-company systems that need to integrate distributed data.

Grid technology is under rapid development and has problems to be solved. It is expected that these problems will be solved by the next version of the Globus Toolkit, version 4. Currently, a JVO system based on the prototype is being developed for trial operation.

Grid technology is expected to be a key technology for next-generation distributed system environments and is rapidly expanding and evolving into business and science fields. Present Grid technology is similar to the Internet in the 1980s before the appearance of the World Wide Web. Scientific researchers benefited greatly from the Internet in those days, even though it only had basic functions such as e-mail, file transfer, and remote terminals. However, no one could anticipate that the Internet would grow into a huge infrastructure and have such a big effect on the business world. Like the Internet, Grid technology is expected to spread explosively as the Grid middleware for applications evolve. Grid technology may possibly be regarded as the fourth technological innovation derived from scientific fields, followed by UNIX, the open-source computer system, and the Internet. It is hoped that efforts will be made to establish methods to quickly apply and develop Grid technology based on the research and development that was done to construct the JVO.

Acknowledgements

We express our gratitude to Naoki Yasuda of the Institute for Cosmic Ray Research of the University of Tokyo and to Yuji Shirasaki, Masahiro Tanaka, and Satoshi Honda of the National Astronomical Observatory of Japan for their guidance during the collaborative development of the JVO prototype.

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