6 Knowledge Processing Technology

6-1 An Overview of Knowledge Cluster Systems

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Today, Web plays the role of a “social memory” with vast amount of information on our social and environmental activities. We believe that we can develop a global-scale knowledge network which can enable us to solve various social and environmental problems, by discovering hidden rules through the comprehensive analysis of vast amounts of data and by combining and unifying individually accumulated data of various domains and organizations. To that end, we advance the development of the next generation’s Knowledge Cluster Systems with the aim of transforming the Web into systems for more intellectually satisfying information processing and rigorous analysis. In this paper, we will explain two major components of our knowledge information infrastructure; the interdisciplinary correlation search base on heterogeneous knowledge and service-oriented knowledge information management base on grid computing.

Keywords
Interdisciplinary correlation search, Service-oriented architecture, Knowledge information management, Knowledge GRID, Knowledge cluster system, Language grid

1 Introduction

In today’s Web, quite a variety of information is available and in addition to existing Web pages, records of communication between users through networks such as blogs or chatrooms, record of lifestyle of people found in online shopping sites or lifelogs, ephemeral environmental information obtained through sensors or the like which changes constantly over time. Web plays the role of a “social memory” in which the vast amount of information for natural environments and social activities is recorded and stored. We believe that we can develop a global-scale knowledge network which enables us to solve various social and environmental problems, by discovering the hidden rules through analysis of vast amounts of data and by combining and unifying individually accumulated data of various domains and organizations. To that end, we advance the development of the next generation’s knowledge processing platform with the aim of transforming Web into systems for more intellectually satisfying information processing and rigorous analysis.

Our Knowledge Cluster System is constituted of computational grid platform and interdisciplinary correlation search engine (Fig. 1). It not only has the old functions of delivering and sharing data like traditional Web, but also it has functions such as, collection of specific data for intended purposes, abstraction of information on various topics and events from assembled data, combination of pieces of information in multiple ways, searching and browsing of the combined information. Assuming you want to know the connection (correlation) between global climate change and public security, all you will have to do in the old search engine will be to search for Web pages that contain “global climate change” and “public security” and then judge for yourself whether the content agrees with

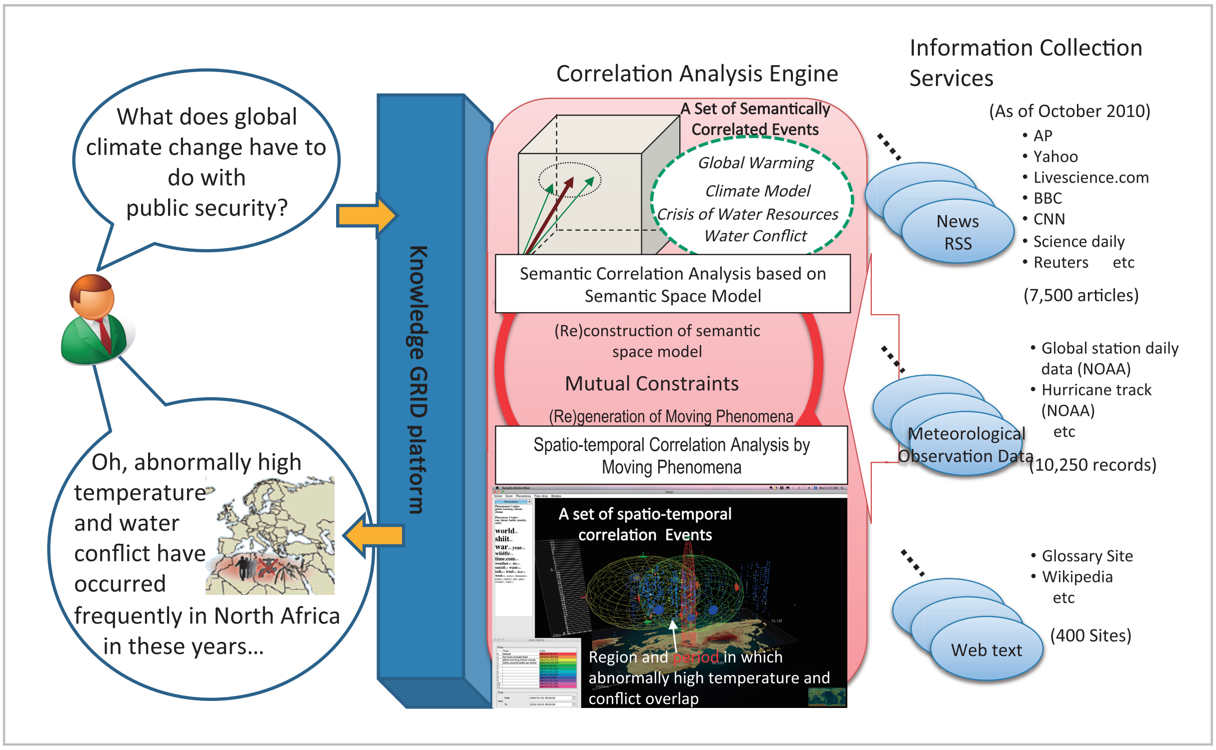


Fig.1 *Correlation search engine by Knowledge Cluster System*

your interest or not. By contrast, the system we are developing helps us to pick out correlating information by extending the scope of contents *unspecified* by these keywords, such as, "These years have witnessed frequent abnormal high temperature and water conflicts in North Africa".

The correlation search engine searches and discovers information from not only Web pages but also vast amounts of data ranging from news to meteorological records etc that are semantically and/or spatio-temporally related to the Web pages query. Since one no longer needs a common dictionary, one is able to discover the relevant correlation between heterogeneous and interdisciplinary data with high scalability. Correlation search engine creates an index for each datum using a variety of features with regard to time, space and theme. In query processing, the engine searches for the best combination of features (we call it "correlation context") and simultaneously it searches for a data set by the use of that combination, which has a higher correlation value. As a result, it finds a data set that shows a high correlation within the context. To see this in the previous context example, "In these years (temporal feature), abnormally high temperature and water conflict (thematic feature) occur frequently in North Africa (spatial feature)". We are proposing a correlation analytic method based upon a semantic space model and a "moving phenomena" spatio-temporal model. The characteristic of both of these models is to be able to discover with high flexibility and high efficiency the best combination of features and a correlating data set by selecting a subspace from the multidimensional semantic spaces.

All the functions of our Knowledge Cluster Systems are implemented on a computational grid platform. We have developed a wide-area grid network connection around the globe and have realized a grid environment based upon service oriented architecture (Fig. 2). On the grid platform, a wide variety of software services for data collection and information extraction, correlation analysis and user interface interaction is developed and deployed in each grid node in parallel. To combine and coordinate these services, one can create various

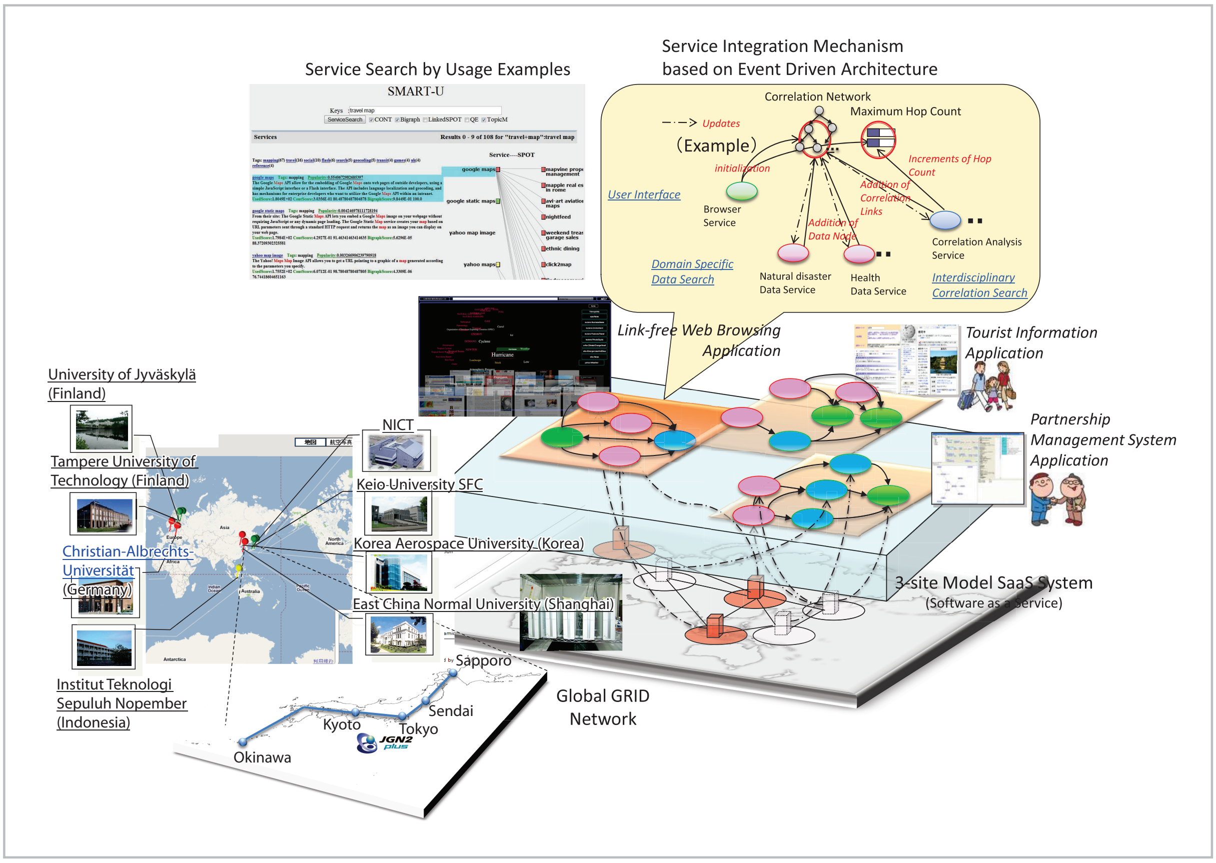


Fig.2 *A grid environment based upon service oriented architecture*

next-generation Web applications. Thus far, we have developed a wide variety of applications such as the “Link-free Web Browsing”, in which the application traverses Web in accordance with correlation instead of hyperlinks. In addition, the Tourist information system navigates information correlating with the query keywords in terms of place, time and the theme. The Partnership Management System collects information broadly from different Websites and patents information on products, services and technology of companies or an organizations and matches up these information under various themes. The grid platform provides a service collaboration mechanism and programming languages for application development. We are also developing a mechanism (service discovery engine) of searching for helpful services based on how the services are to be used in applications.

In Section **2**, we will talk about interdisciplinary cross search technology based upon correlation analysis and in Section **3**, we will talk about service oriented knowledge processing with the use of grid platform. Finally in Section **4**, we will give a summary and discuss on the future perspective.

2 Interdisciplinary cross search based upon correlation analysis

In general, to arrange and analyze pieces of information with regard to a certain event, it is not enough to only acquire information from a domain specializing in that event. It is equally important to assemble relevant pieces of information from various different domains that are derived or are influenced by the original information. For instance, to know something about “global warming”, it is important to collect information not only about natural disaster caused by climate change, but also relevant pieces of information from various domains, such as industries, economy, energy problems and health and education. These pieces of information are collected and provided individually by various Websites. If you search with a traditional Web search engine, you will have to repeat selecting the search keywords for each domain and consolidating an enormous amount of search results. Once a system is made that can search for relevant pieces of information across different domains and displays them simply, it will be easy to understand more comprehensively the various events occurring worldwide.

2.1 Heterogeneous knowledge base integration

Thus far, our research and development was carried out by developing "Knowledge Cluster Systems" [1] that integrates a variety of heterogeneous knowledge bases from different domains dynamically and searches and delivers relevant pieces of information that go well beyond a particular domain. In our heterogeneous knowledge bases integration framework [2][3] (Fig. 3), we define two basic functions in order to realize heterogeneous knowledge base integration.

Intra operation: This does a correlation search within a particular knowledge base. To a concept term given as an input, it computes the correlation strengths of concept terms within the knowledge base and gives as output a set of highly correlated concept terms.

Inter operation: This does a correlation search between two heterogeneous knowledge bases. For instance, inter operation between two knowledge bases, call them knowledge base A and knowledge base B respectively, generates a correlation matrix that describes the relation of mapping between concept terms contained in each base. Then it computes correlations between concept terms in two knowledge bases as a distance within a semantic space (vector space) that is constituted by the matrix.

The combination of these two sorts of basic functions allows us to do a correlation search between heterogeneous knowledge bases with higher scalability. Search results are represented as a semantic correlation network in Fig. 4. In Figure 4, the search starts with "volcano gas" as a query and the intra operation of volcanic disaster knowledge base gives such concept terms within the base as "lava flow", "mud flow", "CO_2", "SO_2", "pyroclastic

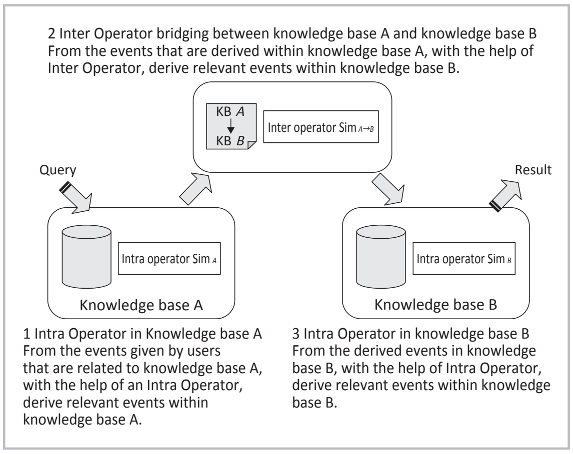


Fig.3 *Interdisciplinary knowledge base integration framework*

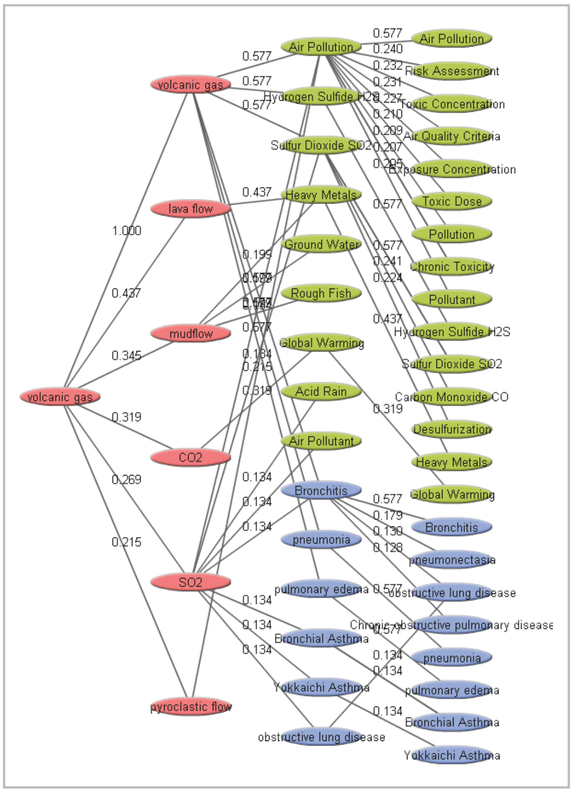


Fig.4 *Semantic correlation network acquiring correlation search results from volcanic disaster knowledge base to environmental and healthcare knowledge base (query: "volcanic gas")*

flow" and so on. Notice that the number in each edge stands for a correlation value. In the next step, an inter operation, which connects volcanic disaster knowledge base to environmental knowledge base, receives these concept terms from the former knowledge base as input and gives as output those concept terms in the latter knowledge base that are highly correlated with the input. Such concept terms include "air pollution", "hydrogen sulfide", "heavy metals", "ground water", "rough fish", "acid rain", "global warming" etc. At the same time, another inter operation, which connects volcanic disaster knowledge base to healthcare knowledge base, gives concept terms in the medical knowledge base that are highly correlated with the same input. Such concept terms include "bronchitis", "pulmonary edema", "bronchial asthma", and "obstructive lung cancer". In the final step, intra operations, which individually correspond to a knowledge base in each particular domain, gives highly correlated concept terms within each domain. As a result, you get a set of concept terms that are highly correlated with a query "volcanic gas" in both environmental and healthcare domains, together with a semantic correlation network that shows the process of their derivations.

The characteristic of our proposed method is the ability to switch via an inter operation, the manner of forming a series of correlation depending on *context*, when doing a correlation search. In the above example, if each inter operation uses a correlation matrix generated from information about global warming, the semantic correlation network of search results represents the process of deriving those highly correlated concept terms in each domain in the context of global warming. We also developed a correlation search in the context of a particular natural disaster (for example, "Unzen Fugendake", "Miyakejima", "Sidoarjo Mudflow" etc). To develop them, we have implemented a mechanism of automatically generating correlation matrix from RSS data (Fig. 5). RSS is used widely for multiple purposes including the delivery of Web news articles. A variety of information is included in RSS data and that enhances the efficiency of RSS as an information source for generating a correlation matrix. The accumulated RSS data are divided into groups based on themes; themes that correspond one by one to the contexts of correlation search. For the combination of concept terms contained in each knowledge base, a positive correlation value to the correlation matrix can be set if sufficient number of combinations appear in the collected RSS data.

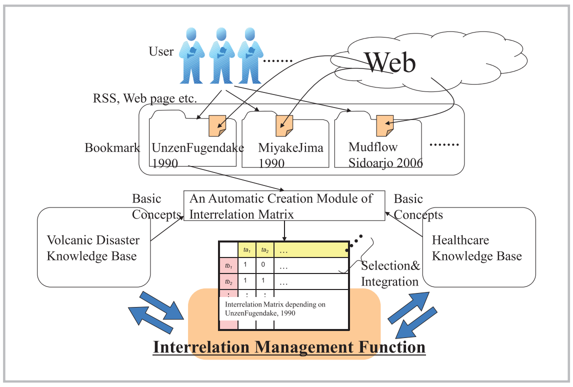


Fig.5 *Automatic creation of correlation matrix using RSS data*

2.2 Link-free browsing

Link-free browsing [3]-[5] is a system that applies interdisciplinary knowledge base integration to Web browsing. In traditional web search, users often fail to even come up with an appropriate keyword in the domain they are not acquainted with and as a result, miss important information. Link-free browsing is expected to solve this sort of problems. Figure 6 is an overview of link-free browsing system. Link-free browsing works in the following way.

1. Content browsing mode
   This mode allows users to browse the content of a Web page, as a normal Web browser does.
2. View point select
   If a user selects and highlights a term that attracts her interest from a Web page displayed in the content browsing mode, the system displays as "view points" possible knowledge bases for correlation search from the term. If the user selects a particular view point, a

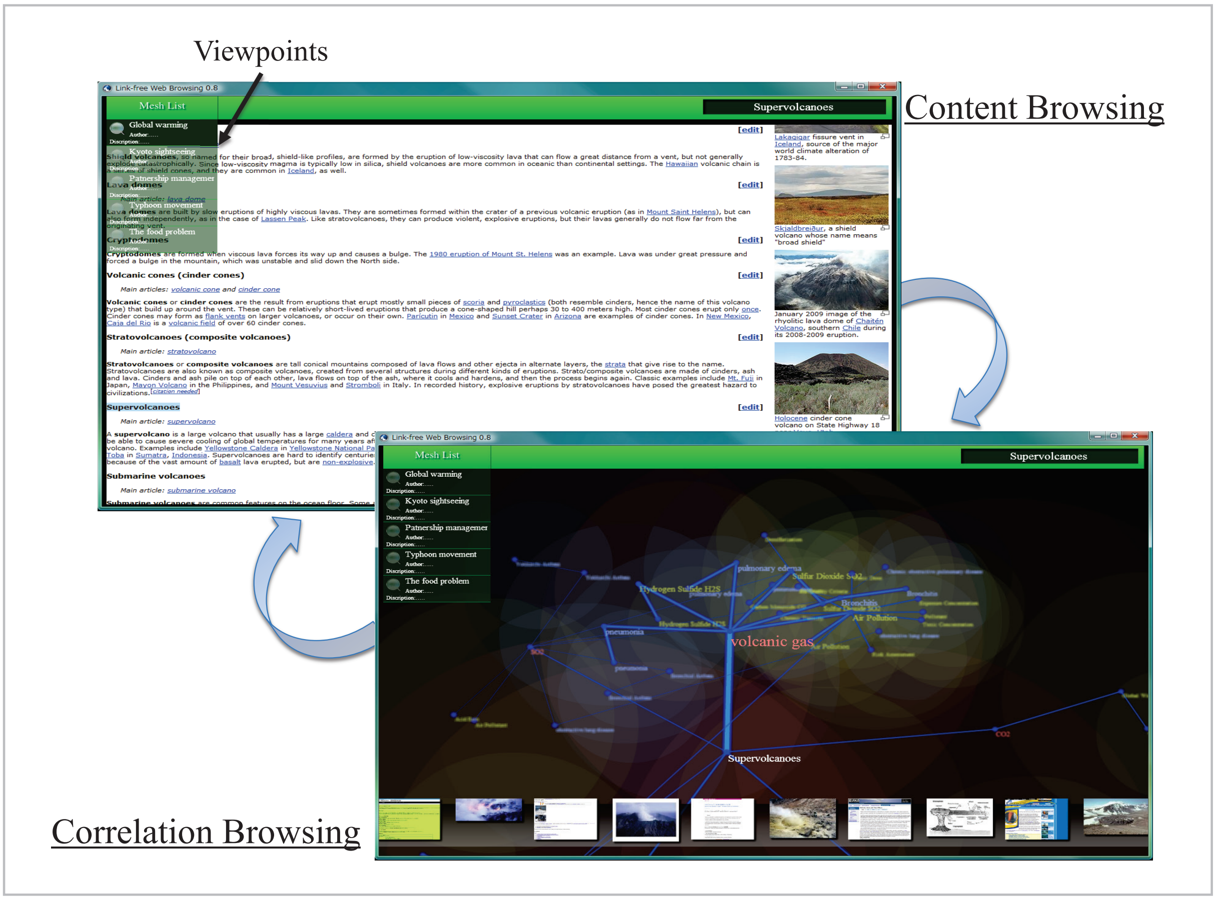


Fig.6 *Link-free browsing system*

corresponding intra/inter operation is set to the system.

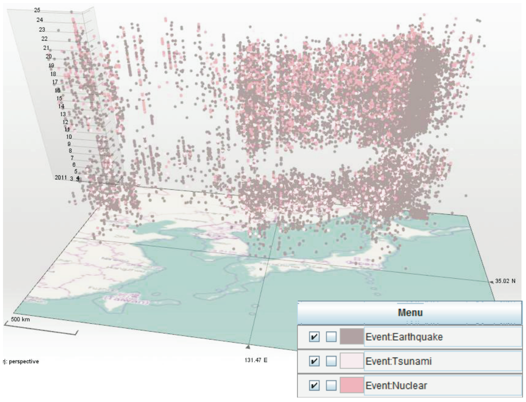
3. Semantic correlation network browsing mode

   The system carries out a correlation search into a variety of domains from the selected term in accordance with view points and generates a semantic correlation network. It thumbnails, at the bottom of the screen, Web pages that correspond to a concept word each node in the semantic correlation network represents. Once the user clicks a thumbnail, the user is directed to a Web page and can move to the content browsing mode.

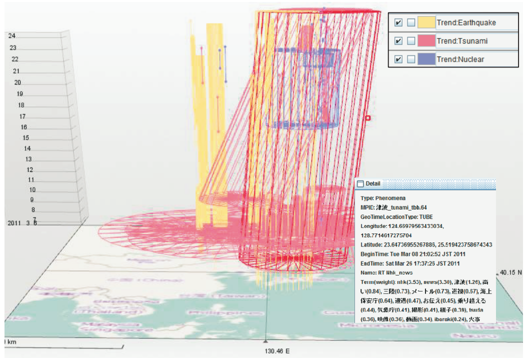
Thus, link-free browsing, by switching between normal web browsing via static hyperlinks and generations or browsing of semantic correlation networks via dynamic correlation search, allows users to repeat Web page browsing and relevant concept search and helps deepen the user's understanding.

2.3 STICKER: Clustering based upon spatio-temporal correlation

In the case of cross search between heterogeneous domains, semantic correlation may not be sufficient. Information on a wide variety of influence of an unprecedented disaster, for example, may be found by looking at the spatio-temporal vicinity of the corresponding data rather than their semantic similarity. Thus, we propose STICKER (Spatio-Temporal Information Clustering and Knowledge ExtRaction) as a way of clustering information based on spatio-temporal correlation [19]. Figure 7 shows the GUI of STICKER. STICKER plots information (so-called event information) (Fig. 7 (a)) on a three dimensional space, which is comprised of geographical



(a) Spatio-temporal distribution on earthquake, tsunami, nuclear data and geo-tagged Tweet. (Data: 03/02/2011-03/24/2011. Horizontal plane: Geographical space, vertical axis: time)



(b) Spatio-temporal clustering result on earthquake, tsunami, nuclear data. Each cluster is wire framed shapes such as cylinder and circle.

Fig.7 *Clustering based upon spatio-temporal correlation using STICKER*

space dimensions and a time dimension, and performs various clustering based upon the nearness and the geometrical relationship within the space. The characteristic of STICKER is that it represents various spatio-temporal constraints in forming a cluster as a shape within the three dimensional space (Fig. 7 (b)). For example, a minimal boundary box (MBB) encompasses points of interest (POI). A circle or a sphere represents a surrounding region of a particular event. A pipe or a corn shapes their temporal movement. A composite shape can be constructed by their combination. Another characteristic of STICKER is that users can visually arrange clustering conditions by manipulating these shapes. Furthermore, users are able to grasp an indirect correlation between more than one cluster, by examining various geometric relationships between these shapes. Containment relationships include simple overlapping, overlapping with the progress of time (joining), leaving, merging, splitting, two shapes' being in parallel conditions at a specific time and space etc. Information contained in each cluster is outlined in a variety of ways, including tag cloud, which presents a set of major keywords, and trend graph, which represents the temporal transition of high frequency words.

The clustering and its manipulation displayed by GUI are performed by Moving Phenomena Database Management System (DBMS) [20]. Moving Phenomena DBMS has a data definition language (DDL) expanded on SQL and a data manipulation language (DML) and defines data models of event information and various clustering operations.

3 Service oriented knowledge processing based on grid platform

3.1 Knowledge GRID platform

In today's network society, knowledge intensive engineering is occasioned by communication and cooperation that go beyond the organizational, national, cultural, and domain boundary. Knowledge GRID [1][6] is information base to solve problems by cooperating in a distributed knowledge processing environment. The concept of Knowledge GRID denotes parallel distributed knowledge discovery and data mining (PDKDD). PDKDD is a grid computing platform with functional layers for discovering distributed knowledge. We have extended this concept in the spotlight of the following points.

Interdisciplinary collective intelligence: On the Web, many people and organizations form a certain community and share and exchange a wide variety of information. Although, various pieces of collective knowledge are accumulated as information assets for each of these networks, these information assets are closed under a particular domain or a particular community. In the case of contingency planning and environment problems, it is necessary to exploit these information assets beyond the boundary of a particular domain and a particular community. It is equally important to reflect “users’ value” using the “architecture of participation” which consolidates data delivered by individual users and stores pieces of information that are actively used and deletes those that are not.

The dynamic formation of Virtual Organizations: Recent years have often seen, especially among various industries and environmental sciences, dynamic sharing of information assets of data and tools by different branches of organizations in cooperatively resolving a common problem. To bring to realization interdisciplinary and dynamic sharing of information assets, a virtual organization (VO) that encompasses multiple organizations is dynamically formed on grid platform [9]. It explicitly defines rules on use of information assets, which dictate who is entitled to use what kind of information asset for what purpose, and brings to reality semi-open information sharing environment.

Service oriented knowledge processing: Service oriented architecture (SOA) [10] is a paradigm that uniformly treat any type of information assets as a service. It is recognized broadly as bringing revolution to the traditional computing environment. Service oriented knowledge utility model [11] is a fundamental technology that helps anybody uses knowledge processing as shared resources at any time and from any location. It dynamically combines knowledge processings, which are transformed into services, in response to the user’s request and task, and changes the structure and the behavior in accordance with the execution environment. Knowledge base also moves from the traditional relation DB to a graph DB or a triple DB, which is able to deal with knowledge expressions with higher flexibility.

3.2 System outline

Knowledge services on Knowledge GRID can be classified into three kinds.

Knowledge discovery service: This implements a mechanism of generating metadata by way of various data analysis methods, such as classification, summary, ontology, with the aim of providing knowledge description of information assets.

Knowledge association service: This generates various correlations among information assets by exploiting concept level descriptions (metadata) of them provided by knowledge discovery service. We develop this type of services based on heterogeneous knowledge base integration framework mentioned in Subsection **2.1**.

Knowledge delivery service: This provides functions of structuring and visualizing output from knowledge discovery services and knowledge association services. Link-free browsing mentioned in Subsection **2.2** is an example this type of service.

Knowledge GRID application is realized by the various combinations of the abovementioned services. Knowledge GRID provides two kinds of service collaboration models.

Workflow model: This defines the procedure of service collaboration and controls execution flows such as conditional branching (if-then-else) and loop (while) often seen in a general programming language. Knowledge grid employs Web service business process execution language (WSBPEL) [12], which is de facto standard for Web service work flow integration.

Event driven model: This determines the kind of data to be shared among different services and defines declaratively what kind of change in what kind of data is relevant and how to if the change occurs. In

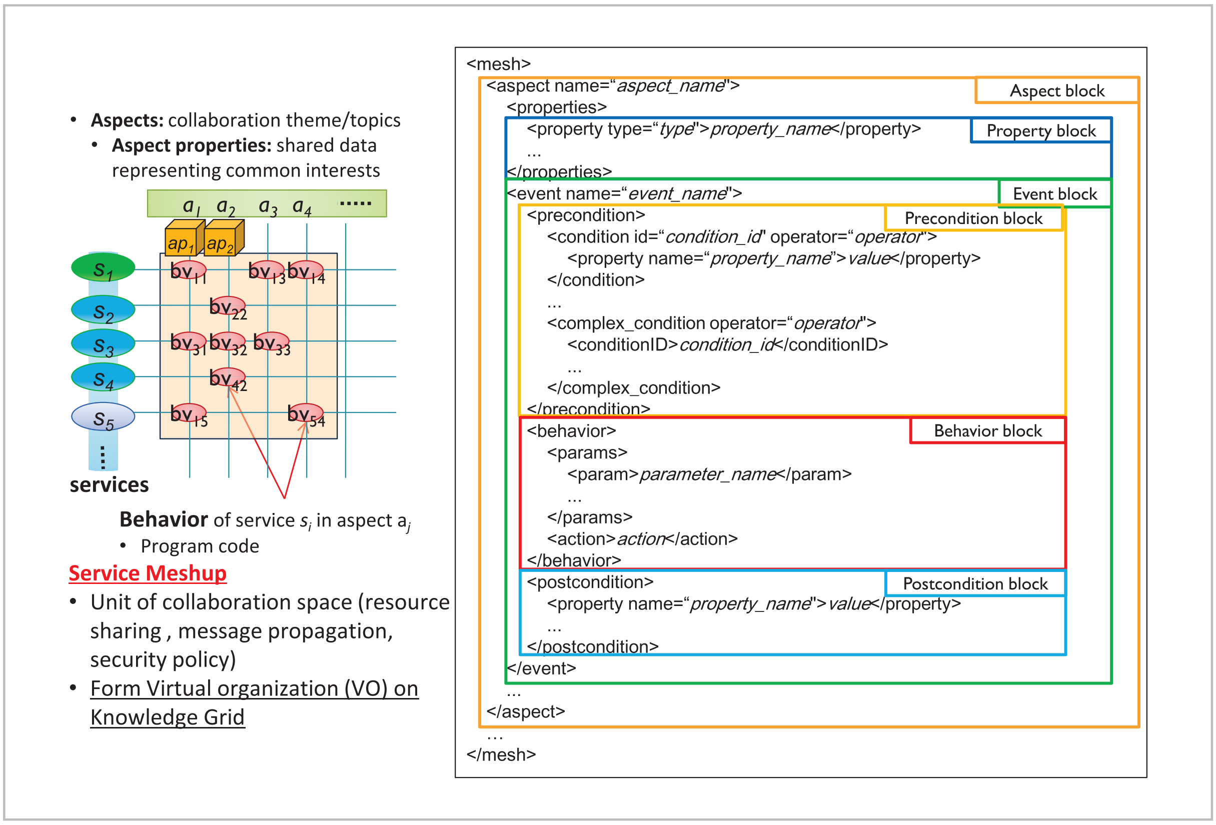


Fig.8 *Description example of Service MeshUp*

Knowledge GRID, event driven model is specialized in letting multiple services to cooperatively exploit information assets and provides a framework (Service MeshUp) of bringing into reality a data-based event driven service integration.

Though these two models are convertible with each other, our Service MeshUp, contrary to the traditional workflow model which is suited for procedural processes like business transaction, fits nicely into self-organizing processes and long-term persisting processes like collective knowledge formation and state monitoring.

In the last half of this section, we will explain Service MeshUp; one of data-centric event driven models. Figure 8 shows an example of Service MeshUp description. In Service MeshUp, an application is constituted of a set of different aspects. Each aspect denotes a single task and a function within the application and has data (aspect properties) shared by various services. The application developer specifies a service incorporated in each aspect and then defines 1) preconditions: the conditions of aspect property for invoking each service, 2) behavior: the action each service executes when invoked on these conditions, 3) postconditions: the update of aspect property after the execution of the service.

Knowledge GRID is constituted of three-tier architecture comprising of grid network, service platform and application. Grid network is implemented by the aid of industry standard Globus Toolkit middleware [13]. Contrary to the traditional grid which is oriented toward high-performance computing cluster, each node of Knowledge GRID is distributed around the globe just like the Web server. These GRID nodes are connected via a secure virtual network and various kinds of knowledge services are independently and concurrently developed in each node. On the other hand, service platform plays the roles of implementation, de-

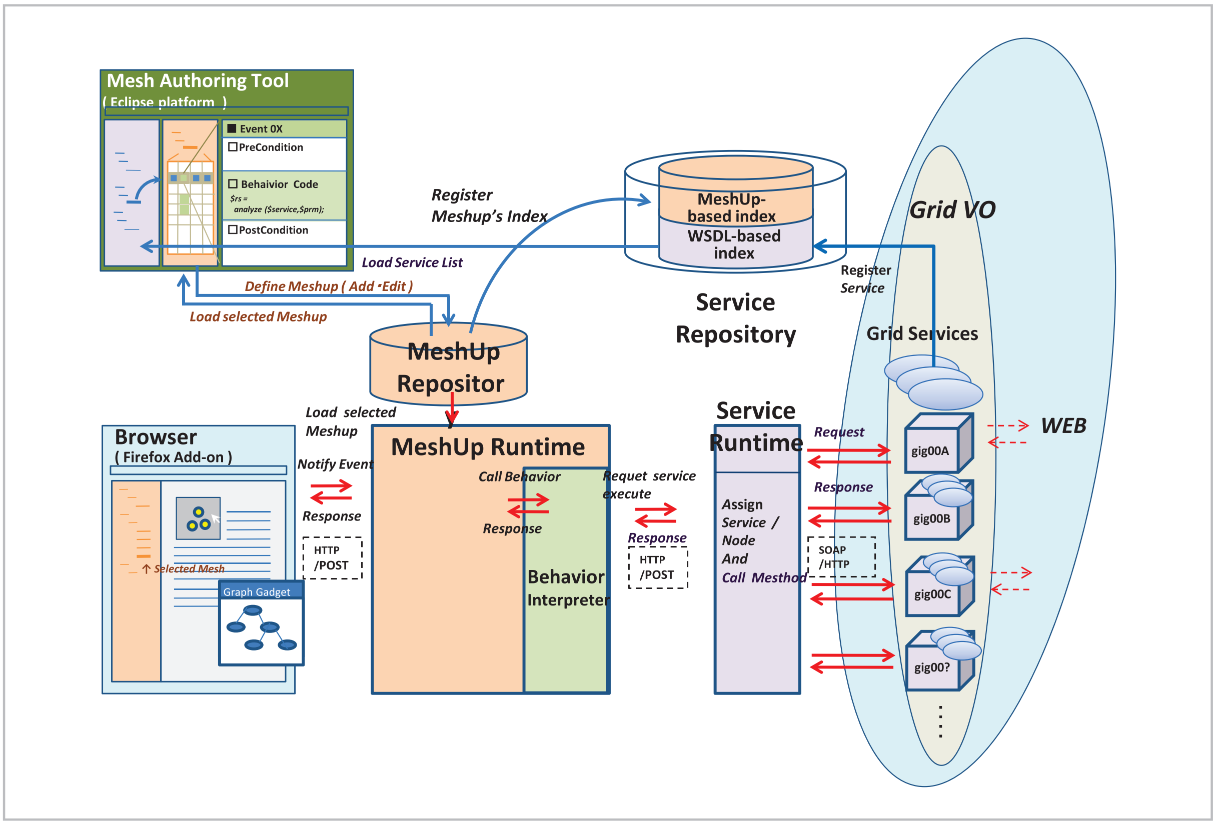


Fig.9 System architecture of Knowledge GRID service platform

ployment, search and integration of knowledge service. Service platform is constituted by the following modules (Fig. 9).

Mesh runtime: This interprets Service MeshUp description and performs knowledge service integration.

Mesh repository: This stores Service MeshUp description and searches them.

Service runtime: This invokes a knowledge service on a local or a remote GRID node.

Service repository: creates a catalogue for knowledge service and assigns the name of the service, which is used for Service MeshUp description and end-point-references, which Service runtime uses to call out a service.

These modules work in the following order. First, Mesh runtime interprets Service MeshUp description and does a search on the Service repository and from the name of the service solves end-point-references (EPRs). On the basis of these EPR sets, Mesh runtime creates VO which is constituted by a group of GRID nodes for which each service is deployed. In this VO, secure sharing of aspect properties and service invocation takes place. Once VO is formed, aspect properties are initialized by Mesh runtime and the execution process of Service MeshUp starts. During the execution, Service runtime invokes a knowledge service. Service repository is managed nonintensively and information of knowledge service is registered first on a local GRID node and then delivered to another GRID node.

3.3 Language Grid

Language Grid [14] is a service oriented multi-language infrastructure with the aim of supporting different cultural collaboration. The aim of the Language Grid is to transform the current situation, in which dictionary data and machine translation software, distributed as language resources by CDs and downloadable services, into language services that can be accessed easily once connected to the internet, and to help users properly combine the language services in accordance with the environment of different intercultural collaboration. Language grid provides a "base software", which enables you to collect, share and integrate language services, and "different intercultural collaboration environment", which makes language services that are registered on the base software easily available to users (Fig. 10). Language grid especially lays emphasis on the following points.

Building a service-oriented multi-language infrastructure: To accumulate and share language services, we need a base software, which integrates services on the basis of atomic service that has standard interface. Furthermore, users must be able to easily develop an application system, which supports different intercultural collaboration by the use of these language services. Language grid is comprised of 4 layers [16]; P2P service grid, atomic service, combined service [15], application system. Since P2P service grid [17][18] enables information sharing among core nodes, a service user can use from any core node the same service and a service provider can uniformly control the access from any core node.

Institutional design of operational model: Service-oriented collective intelligence contains a variety of stakeholders. Each user has different requirements and each provider has a different policy. In order to encour-

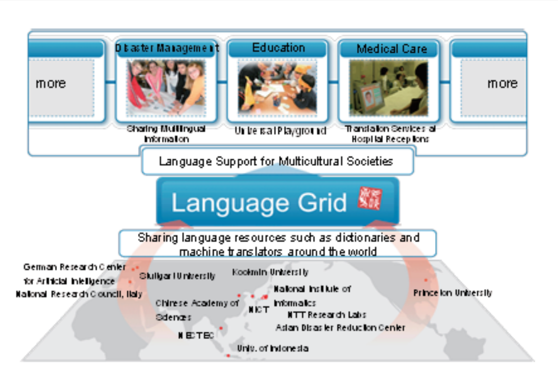
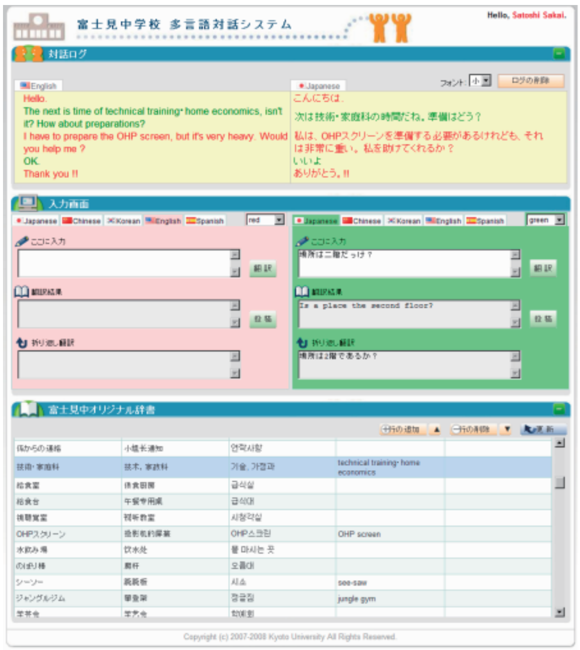
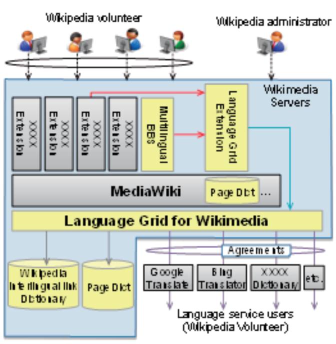


Fig.10 Overview of Language Grid



(a) Language Grid Playground

(b) Case study of Language Grid Toolbox



(c) Multilingual Liquid Thread System

Fig.11 Applications of Language Grid age these heterogeneous stakeholders to cooperate, the manager must design an operational model which takes into consideration the incentives of both the user and the manager. Language grid proposes an operational model for enabling heterogeneous stakeholders to cooperate. This operational model is designed to relate the incentive of a service user to the incentive of a service provider. In addition, it proposes a federation management model, which makes possible the cooperation among multiple management organizations, to improve accessibility to language services.

The practice of user participatory design: The more the number of language services provided, the more the benefit a user enjoys through the services. That means that to form a service-oriented collective intelligence, it is necessary to encourage users and communities to actively participate in it. Language grid accelerates the user participatory design with the help of service-oriented approach and universal cross-intercultural collaboration supporting tools. As a matter of fact, some schools and NPOs have developed a special cross-intercultural collaboration environment using language grid playground (Fig. 11(a)) as well as language grid toolbox.

Though language grid is a multi-language infrastructure resting on service-oriented collective intelligence with the aim of supporting cross-intercultural collaboration, its base software and operation model is not specialized in language only. It is applicable to other domains by defining new service interface. We are planning to engage in the development of service platform, which encourages the use of big data, on the basis of service-oriented collective intelligence, by developing data service that takes large amounts of scientific as well as archive data and a service for analyzing large amounts of data.

4 Future perspective

eScience and data-intensive science is said to be the fourth paradigm of science following after experimental science, theoretical science and computer science. It is a science which aims to discover and verify hidden rules and relevance by analyzing a large amount of data across a wide variety of domains. It stresses social necessity and tries to discover correlation between science related data and society related data with the aim of applying knowledge accumulated through traditional scientific investigations to users' decisions and behavior supports. For example, it takes care of such questions as, "What is the social activity that is influenced by a certain natural disaster?". Since it is difficult to construct a scientific model to help solve this sort of enquiry, the technology of discovering with high flexibility and scalability correlation between data in heterogeneous domains is expected to work. Against the backdrop of this, we are doing research and development for cross domain data management service in distributed information processing base. In particular, we are doing research and development for dealing with scientific data of space and earth environment and social data taken from, say, articles in newspapers.

On the other hand, grid platform is making progress as a "value creating network" service integration platform in the New Generation Network (NWGN). We are developing a technology which extends the traditional service computing paradigm and which abstracts as services in any ICT resource, ranging from server, storage, network, terminal to software, means of communication, manpower and which enables us to seamlessly integrate services without being bothered by network restrictions. In addition, by implementing directly on the network platform the element technologies (service addressing, messaging, service discovery, and collaboration control) which constitute service integration, we are developing a method of realizing with high performance and scalability a horizontal integration between services and a vertical integration between ICT resources.

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(Accepted June 14, 2012)

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