Available online at www.sciencedirect.com
ScienceDirect
Expert Systems with Applications 34 (2008) 2019–2028
Expert Systems with Applications
www.elsevier.com/locate/eswa

Apply ontology and agent technology to construct virtual observatory

Ruey-Shun Chen [a], Duen-Kai Chen [b,*]

[a] Department of Information Management, China University of Technology, Taipei 116, Taiwan, ROC
[b] Institute of Information Management, National Chiao Tung University Hsinchu 300, Taiwan, ROC

Abstract

The need to deal with abundance and heterogeneous information is apparent in the astronomy community. The virtual observatory (VO) concept is the astronomical community's response to alleviate this problem and Web services serve as one of the most important VO enabling technologies. However, one of the limitations of Web services is the lack of semantic description of its content, thus prohibits its ability to understand the queries and its inference capabilities. This study proposes to develop a conceptual framework based on multi-agent systems and ontology technology, in order to create a VO with semantically enriched Web services. Intelligent agents represent: (1) users to submit requests (2) perform semantic matching in between users' requests and Web services registered within agent platform, and (3) activate a serial of Web services. The capabilities offered by multi-agent systems to query and invoke semantically enriched Web Services is also exploited in this study. To validate the proposed framework, an illustration example is implemented in JADE agent platform to demonstrate how the proposed framework operates and how it benefits the research regarding to auroral images.

Keywords: Multi-agent systems; Ontology; Web services; Virtual observatory

1. Introduction

The need to retrieve and process exponentially increasing of information is becoming apparent and is having a huge impact on professions that rely on distributed archived information. This is true especially for the auroral physicists who depend largely on the shared image information content, for example, images from different locations, with different sizes, intensity, and morphology of the auroral oval. Therefore, how to retrieve needed information, access to language independent software for image processing and furthermore, share the research results becomes an essential topic. The virtual observatory (VO) concept is the astronomical community's response to the information abundance. VO is an emerging, open, web-based, distributed research environment for astronomy with massive and complex data sets.

Web services serve as one of VO enabling technologies; however, there are some limitations of the traditional Web services. One of the limitations is that Universal Description, Discovery and Integration (UDDI) and Web Services Description Language (WSDL) do not provide semantic description of its content. UDDI is characterized for its lack of semantic description mechanisms, such as semantic interoperability, explicit semantic models to understand the queries and inference capabilities (Baousis et al., 2006). The same limitation also applies to WSDL, for WSDL does not contain information about the capabilities of the described Web services.

This paper proposes to develop a conceptual framework based on multi-agent systems and ontology technology to assist auroral physicists work with semantically enriched web services and realize the concept of VO. The above mentioned framework can be used for retrieving necessary information, dynamically allow users to define descriptors and operations most appropriate for their purposes, for

* Corresponding author. Tel.: +886 3 5712121x57427; fax: +886 3 5723792.
E-mail addresses: rschen@iim.nctu.edu.tw (R.-S. Chen), cdk@iim.nctu.edu.tw (D.-K. Chen).

0957-4174/$ - see front matter
doi:10.1016/j.eswa.2007.02.018

example, comparison of physical features between auroral images, regardless of their source or data representation. In other words, the proposed framework complies with the VO concept. The goal of the proposed framework is to assemble data archives and services, as well as data exploration and analysis tools.

Recently, ontology and agent technology have been widely applied to various domains. For example, Jing, Bi, and Wu (2005) pointed out that Geospatial information services may provide the data and function services to handle with basic geo-tasks, in the meanwhile, user and software agent should be able to discover, invoke, compose and monitor geospatial resources offering particular services and having particular properties. Web services are turning into the dominant means for connecting remotely executing programs via Internet and commonly used machine readable representations such as XML. The Web Ontology Language for Services (OWL-S) is imported to express the process ontology and process control ontology. In virtue of the Web services semantic markup, develop the agents to support the automatic reasoning and fulfill the composition of Web Services and inter-operation is possible.

The contributions of this paper are twofolds. First is to provide an environment which is easy to obtain and share information with the assistance of ontology and multi-agent systems via dynamically discover and invoke semantically enriched Web services. Furthermore, it is believed that the proposed framework could easily be extended for similar domains. Second, the proposed framework utilizes multi-agent systems and ontology for share, retrieve and process information. Adopting multi-agent systems to assist information processing can achieve advantages such as robustness and scalability. The proposed framework enhances flexibility and extensibility owing to its modular design. Modular design means that the module within the architecture can be substituted by better and newer modules when necessary, thus ensuring the flexibility and extensibility. To facilitate information sharing among different research projects, the proposed framework develop ontology which includes standardized, community-accepted descriptions of the information. Such ontology served as the basis for information content definitions that can be used repeatedly.

The rest of the paper is organized as follows. Section 2 introduces the background on Web services, VO, and space-based auroral image research; ontology technology; multi-agent systems-especially focuses on the agent communication and coordination. Section 3 presents how the proposed framework assists auroral physicists in retrieving and processing images from heterogeneous data sources by incorporated ontology and multi-agent systems technology. Section 3 also gives the overview of the proposed framework; the types of agents consisted in the framework, the functionality of each agent. Section 4 highlights the software solution and implementation to the proposed framework and provides practical examples to illustrate how images from different sources (e.g. ultraviolet imager (UVI), far-ultraviolet imager (FUV)) can be retrieved and processed. Section 5 gives the conclusion and identifies future works.

2. Literature review

2.1. Space-based auroral image, virtual observatory and Web services

A conceptual architecture of a VO is shown in Fig. 1. From a space physicists' viewpoint, one should be able to discover the available data for their study, which generally reside in distributed archives, federate them, and pipe the output into a set of data mining/knowledge discovery in databases analysis and discovery tools. These services may be implemented as Web services, and may involve use of AI and machine learning tools, coupled with sophisticated visualization environments (Djorgovski, 2005).

W3C (2004) defines web service as "... a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically WSDL). Other systems interact with the Web service in a manner prescribed by its description using simple object access protocol (SOAP) messages, typically conveyed using HTTP with an XML serialization in conjunction with other Web-related standards".

A Web service is an accessible application that other applications and humans can discover and invoke. Web services are nowadays emerging as a major technology for deploying automated interactions between distributed and heterogeneous applications. Various standards back this deployment, including

- WSDL – support the definition of Web services.
- UDDI – support advertisement to the community of potential users.
- SOAP – binding for invocation purposes.

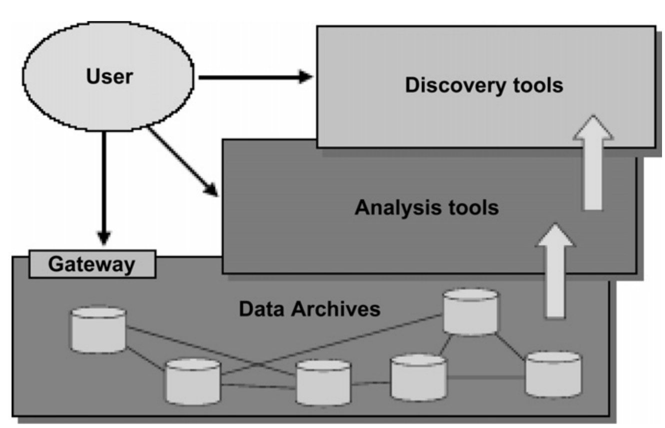

Fig. 1. Conceptual architecture of virtual observatory (Schlenoff et al., 2005).

One of the examples for facilitating Web services as an enabling technology for VO described in Ohishi et al. (2004). The authors in Ohishi et al. (2004) depicted how UDDI, which serves as yellow page services, is adopted to establish Japanese virtual observatory (JVO).

2.2. Ontology

Ontology is an agreement about a shared conceptualization, which includes frameworks for modeling domain knowledge and agreements about the representation of particular domain theories (Huhns & Singh, 1997). Ontology is an esoteric concept borrowed from philosophy by the Artificial Intelligence/Information Technology communities. In this study, we adopt the definition of ontology as "a way of describing all things in common across a collection of similar objects". Ontology served as standardized, community-accepted descriptions of the information content. There existed previous attempts to apply ontology in the field of image processing, in Soo, Lee, Yeh, and Chen (2002), a framework of utilizing sharable domain ontology and thesaurus to help the retrieval of historical images of the First Emperor of China's terracotta warriors and horses was presented. Ontology has also been used in Earth Sciences and Geographic Information Systems (GIS) applications to organize and allow inter-comparison of remote sensing data sets from disparate detectors (Fonseca, Egenhofer, Agouris, & Camara, 2002).

The reason why ontology is essential to the intelligent agents is that it can provide a shared virtual world in which each agent can ground its beliefs and actions. That is why ontology is becoming increasingly recognized as a crucial element of scalable multi-agent system technology. Recently, there are plenty of literatures (Bailin & Truszkowski, 2001; Bravo, Perez, Sosa, Montes, & Reyes, 2005; Obitko & Marik, 2002) which highlight the crucial role ontology played in the development of multi-agent systems.

2.3. Agent technology

According to Jennings and Wooldridge's (1998) definition, an agent is a computer system situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives. Agent systems can be further classified either single-agent or multi-agent systems. Agent systems, particularly multi-agent systems, are subfields of distributed artificial intelligence (DAI) research, and have existed under AI for two decades (Chen, Chen, & Lin, 2005). Generally, DAI is broken into distributed problem solving (DPS) and multi-agent systems. Research on designing and developing multi-agent systems focuses on the interaction between agents. Topics frequently discussed in this area of research include agent action, the relationship between agents, multi-agent system architecture and the environment in which the multi-agent systems exist; interactions among agents within the multi-agent system, and agent adaptation ability. Coordination, negotiation, cooperation are three common interactions among agents in multi-agent systems.

Regarding the application of software agents, Jennings and Wooldridge (1998) noted that "agent are being used in an increasingly wide variety of applications, ranging from comparatively small systems such as email filters to large, open, complex, mission critical systems such as air traffic control". For example, Lee, Yun, and Jo (2003) proposed an auction agent system using a collaborative mobile agent and a brokering mechanism called Mobile collaborative auction agent system (MoCAAS), which mediates between the buyer and the seller and executes bidding asynchronously and autonomously.

In the past decade, academic communities have witnessed a proliferation of software agents with widely varying specialties. Agent technology is a key area in artificial intelligence research. Today, a software agent generally means a software program that accomplishes a task on behalf of its user. Multi-agent systems along with ontology have been applied for supporting distributed decision making in several fields, such as manufacturing, business and engineering. For example, a cooperative multi-agent platform was introduced in Soo, Lin, Lin, and Cheng (2005) to support the invention process based on the patent document analysis. There are also studies abundant in integrate ontology with agent technology. Wu, He, and Jin (2005) proposed to build an open, large-scale and interoperable distributed intelligent medical diagnosis and therapy system in the context of a wide-area network such as the Internet, the paper studies integrating mobile agent and ontology with Web Services, using ontology as a standard web service, which avoids misunderstandings in agent communication. Furthermore, it assures the correctness of matching agent services according to semantics accurately in service register server like the UDDI registry. Schlenoff, Washington, and Barbera (2005) developed intelligent ground vehicle (IGV) ontology. The goal of their effort was to develop a common, implementation-independent, extendable knowledge source for researchers and developers in the intelligent vehicle community. Malucelli, Palzer, and Oliveira (2005) in their paper, combines the use of ontology and agent technologies to help in solving the semantic heterogeneity problem in e-commerce negotiations. The proposed approach aims at creating a methodology that assesses lexical and semantic similarity among concepts represented in different ontologies without the need to build an a priori shared ontology. Day et al. (2005) described an intelligent tutoring agent (ITA) that uses the ontology, INFOMAP, and question answering techniques through the Instant Messaging platform for the "operating system" course.

In virtue of the semantically enriched Web services, develop the intelligent agents to support the automatic reasoning and decision making, as well as fulfill the composition of Web services and inter-operation is possible.

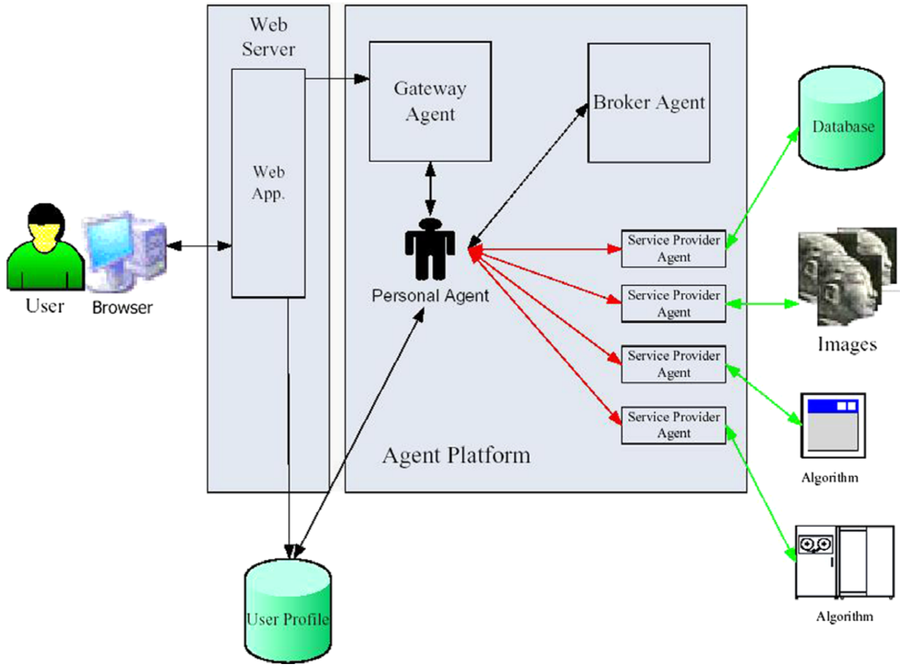

Fig. 2. Proposed system architecture.

3. Apply ontology and agent-based architecture to build virtual observatory

In this section, we first describe how the proposed framework operates. Afterwards, the functionality and internal structure of the agents and components are depicted.

As illustrated in Fig. 2, the proposed framework mainly consists of the web server and the agent platform for all the agents to reside in. In a typical operational scenario, the user may send the request specifying some user defined criteria through the browser, as same as using any of currently existing web application. The advantages of using browser to connect to the proposed framework are easy to use and to ensure that users can be accommodated without having agent platform or any additional programs (e.g. Java Runtime Environment) installed on their client side. The web application also provides services such as user account creation, user login, logout and creation of user profile.

Web server receives the request and then sends it to the Gateway Agent. The role of the Gateway Agent here is to connect web application and agent platform in a transparent manner; it serves as an intermediary service. Gateway Agent allows the web application to invoke agent; translating the HTTP compliant messages to the Foundation for Intelligent Physical Agents (FIPA) compliant Agent Communication Language (ACL) – and vice versa – in order to let Web services and agent technology work together. Personal Agent, as describe in Fig. 3, should be capable of interpreting user's intention. Once the Personal Agent decomposes the user's request into subtasks, it then send the request to the Broker Agent and searching for Service Provider Agents capable of accomplish the aforementioned subtasks. Broker Agent allows Service Provider Agents to post its services. After finding appropriate agents to perform the subtask, Personal Agent then sends request to the target agent and starts to negotiate with the target agent directly. When all of the subtasks had been fulfilled, then Personal Agent will send result to Gateway Agent and Gateway Agent then return the result to user via web page.

After introducing the overview of the proposed framework; the types of agents consist in the framework and its functionalities are describes as follows.

3.1. Personal agent (PA)

The PA serves as a representative for users in agent platform. The main purpose of a PA is finding and executing services and delivering results to the user. A PA is composed of the following components:

- Agent communication module, agents should be able to communicate with each other via ACL. Agent communication module facilitates interaction with Gateway Agent, Broker Agent, and all potential Service Provider Agents.
- Domain knowledge base specifies the autonomous behavior of the PA. It contains the information to guide the PA to accomplish the task delegated by the user.
- Ontology database is used to store ontology for PA to facilitate query and invoke semantically enriched Web services.
- User intention module can be further broken down into User log database, Learning module and User preferences database. The aim of this module is to provide

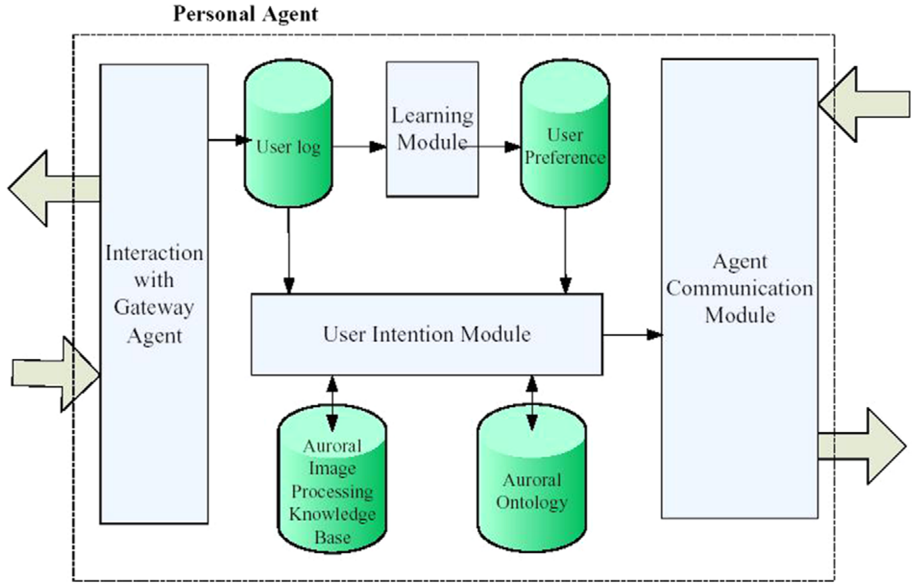

Fig. 3. Personal Agent internal architecture.

customize services for each user and attempt to be able to provide the user with more satisfactory services in the future. To be able to assist end user to complete its goal. This is done by ontology and image processing knowledge base, as well as the learning capability build within the PA. Being intelligent agent, the PA should also able to improve itself through self-learning. The focus of the learning module is to learn user's preferences and profiles in order to provide more accurate assistance. The learning source is provided by the user's log, which is the history of the user's actions on the agent platform. Ontology let allows the agent share the same concept of as the domain expert. The learning mechanism will assist agent in identifying the user's preferences.

3.2. Service provider agent (SPA)

The service provider agent serves as a representative of an existing web service in the agent platform. It provides the web service to interested users and maintains a description of the web service expressed in WSDL and ontology, such as Web Ontology Language (OWL). The WSDL description is facilitated to find the necessary definitions for Web services' successful invocation, while OWL is used to enhance the expressiveness of WSDL in terms of semantic information.

3.3. Gateway agent

This framework presents a Gateway agent for connecting intelligent agents and Web services in an automatic, transparent manner. This Gateway agent allows Web services to invoke agents by translating Web services' requests to agent communication language encodings, and enable automatic, transparent connection between these two technologies. In other words, Gateway agent serves as Web services and agent platform's bridge. Integrating Web services and intelligent agents generates the foreseeable benefits of connecting these two application domains. Once the interconnection is established, intelligent agent concepts and technologies will help enable new, advanced operational and usage modes of Web services. Service invocation by the Gateway agent depends on the OWL description of the service requests. OWL is used to enhance the expressiveness of WSDL in terms of semantic information. OWL is used to specify the input and output ontologies, enabling an advanced service capability search, and find the necessary definitions for successful Web services invocation.

3.4. Broker agent

Service matching along with ontology and ACL assure the correctness of matching agents and Web services according to semantics in service register server like the UDDI registry. Brokering is one of the most significant discovering mechanisms among autonomous, intelligent agents. The main task of Broker agent is to interpret queries from requester and matches capabilities provided by service provider. The brokering process can be categorized into two steps. First, broker agent extracts required capabilities from the query send by PA. Then it compares and matches these required capabilities with what service providers can accomplish. Broker agent extendeds the traditional matching mechanism by finding service providers by capability or functionality rather than simply by name. Service providers register their capabilities within Broker agent, which stores all the registries in a local knowledge base. If capabilities change or the service providers no longer provide the service, then broker agent maintains

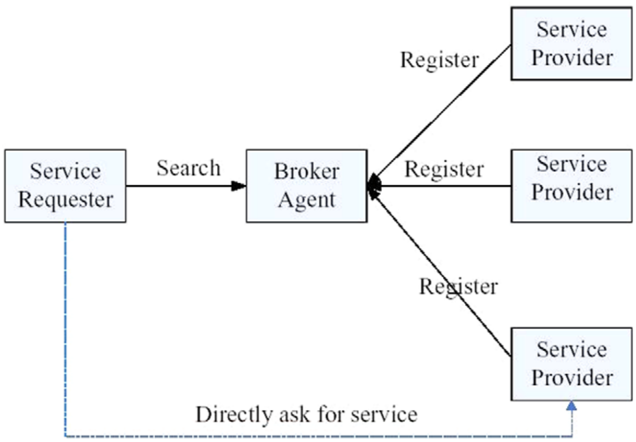

Fig. 4. Service request and service provider matching.

or deletes the service registries. Fig. 4 illustrates the brokering process.

4. Illustration example and discussion

4.1. Illustration example

In this section, an illustration example is provided to demonstrate how the proposed framework operates. In a typical scenario, an auroral physicist compares two images from two different imagers, UVI and FUV. The detector-specific structural details are sufficiently different between imagers that comparison of the information content such as the size of the oval can be difficult. The steps to accomplish the comparison are listed in Tables 1 and 2 summarizes imaging characteristics of these two imagers.

The typical workflow can be described by Fig. 5. During the past, physicists must be able to master all the image databases management systems, related image processing algorithm and be able to manipulate the image according to the specification requirement. Image processing algorithms could be implemented in different programming languages, for example, backgrounds remove and flat field correction mentioned in the workflow were implemented

Table 1
Image comparison processes

User selects time range and spatial location	
Access/find data files for Imager 1 (I1)	Same for Imager 2
Select records within time range for I1	Same for Imager 2
Process I1 records to convert from stored format to science format. Includes background removal, calibration, flat-field correction, and any other instrument-specific corrections	Same for Imager 2
Interpolate image to requested time	Same for Imager 2
Select region of interest in interpolated image that matches the requested spatial location	Same for Imager 2
Summarize ROI, e.g. mean and standard deviation of all pixels within ROI	Same for Imager 2
Compare values from both cameras	

Table 2
Comparison of imaging characteristics for contemporary auroral imagers.

Imager	Frame rate (s)	Image size (pixels)	Imaging method	Spatial resolution (Apogee)
Polar/UVI	37	200×228	Snapshot	40 km
Image/FUV-WIC	120	256×256	Time Delayed Imaging	100 km

in IDL, and calibration was implemented in C++. Thus, physicists sometimes need to install or even recompile the program and make it work in a local environment.

In our proposed framework, first of all, the workflow is according to the following steps.

Step 1, physicist gets to select time range and spatial location of the images to be compared through a browser. The client system is implemented in JSP and Servlet technology.

Step 2, if the user is the first time user, Gateway Agent will create a new account and profile, as well as a new PA for this specified user. Then the auroral physicist's PA decomposes the task "compare two images" into the process mentioned above through the help of Auroral Image Knowledge Base.

Step 3, PA sends the request to the Broker Agent for matching process, to see if there exists any needed Data and Functional Agents (In this illustration example, SPA can be further categorized as data agent and functional agent. The former provides data retrieval and the latter provides variety of other functionalities.).

Step 4, after the matching services provided by Broker Agent, the PA first sends a Call-For-Proposal to all the potential Data Agent (representing which imager) to determine which Data Agents have the image that satisfies the user's request. Some of the Data Agents respond with Propose-essentially, detail description of the imager and its capability to fulfill the user's request. The PA then chooses those imagers match user's request.

Step 5, PA then sends the user's query to Data Agents as a service request. Now it is the Data Agent's turn to interpret and try to fulfill the request. After receiving the result from Data Agents, the PA can apply image processing algorithms, such as image background removal, calibration, flat field correction, to the images.

Step 6, in order to do so, again, the PA sends a Call-For-Proposal to potential Functional Agent (representing image processing algorithm) which can be helpful in satisfying the user's request. Some of the Functional Agents respond with Propose, and PA decide which Functional Agent is most appropriate to perform the image processing according to the user's preferences (such as processing time or accuracy). After receiving the response from the Functional Agent, the PA then represents the result to Gateway Agent, and Gateway Agent then sends the result to user via JSP page. Such process can be described by the flowchart listed in Fig. 6.

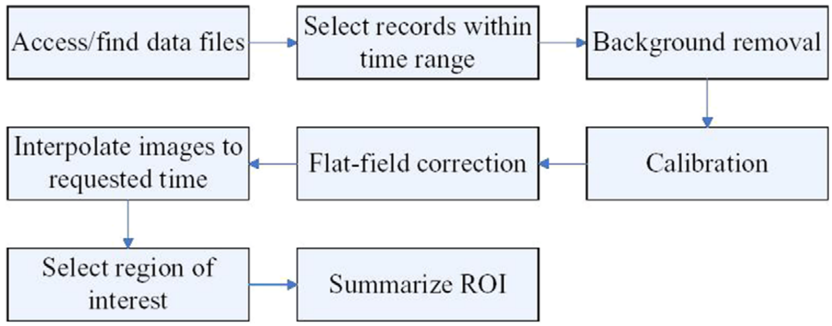

Fig. 5. Image comparison workflow.

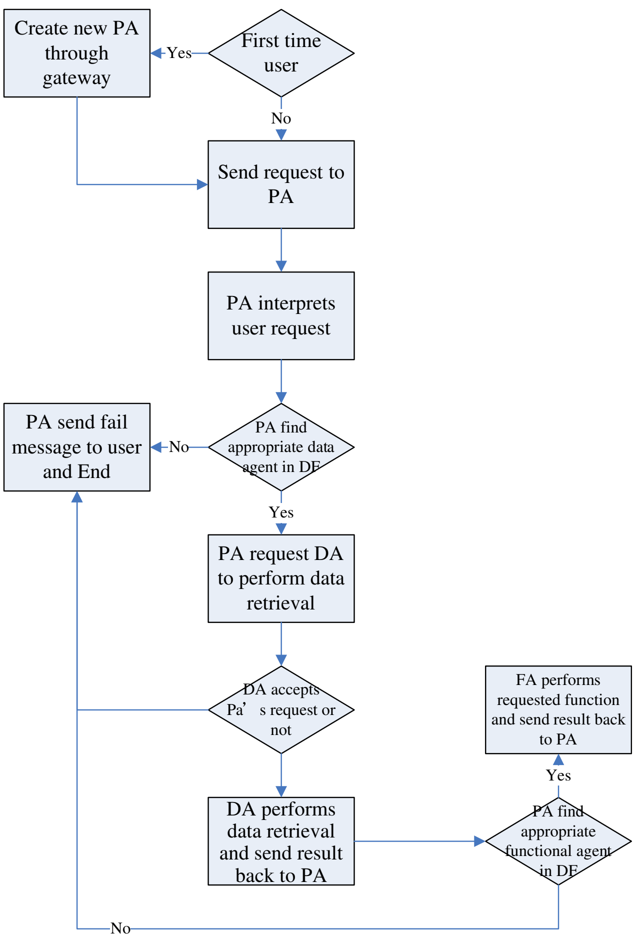

Fig. 6. Workflow of how illustrated example is accomplished.

We implement the prototype with JADE and Tomcat web server to demonstrate the efficacy of this framework. Currently, JADE is perhaps the most pervasive agent system in use, especially in the context of research driven applications. JADE is an open source, FIPA compliant agent platform designed to be a middleware solution for developing agent-based software. Fig. 7 illustrates how agents in the prototype communicate with each other via FIPA compliant ACL. We use Protégé as our ontology editor. Protégé, developed by Stanford University, is an ontology editor, a knowledge-base editor, an open-source, Java tool. One of the advantages of Protégé is that it provides an extensible architecture for the creation of customized knowledge-based applications. The reason for chosen Protégé was due to its strong user community and its ability to support the OWL as ontology representation. The Sniffer agent, a JADE tool which is basically a FIPA-compliant Agent with sniffing features in order to track messages exchanged between agents in a JADE based environment, was employed to verify the validity of the model proposed in this paper. Every message exchanged between agents implies the execution of the model, can be tracked to view in runtime. Fig. 8 drawn by Sniffer agent tool from JADE depicts the message exchange between agents.

4.2. Discussion

Comparing the user behaviors-in both traditional means to handle the image retrieval, image processing and via proposed framework – in the scenario described above, it is believed that the workload of the users can be alleviated. Fig. 9 describes the steps to be accomplished in order to perform analysis for two images from two imagers.

Note that in the proposed framework, the tasks to be accomplished within the dotted rectangle are handled by the multi-agent systems. This implies the following advantages for the users.

(1) Web services solve the problem of obtaining (including find, install or even recompile) the appropriate software to retrieve and process the images.
(2) The auroral image process knowledge base can be facilitated for the PA to choose appropriate Web services to perform image retrieval and image process for different images from different imagers and with different image specifications. In other words, users may invoke a set of services. By this means, users do not have to be familiar with all the imagers' specification to choose the appropriate tools to accomplish the pre-processes for the analysis. This is an explicit advantage, since collaboration between various image teams is common and users might not be familiar with other imager's specification and related image processing algorithm. The proposed framework allowed users to focus on their research and

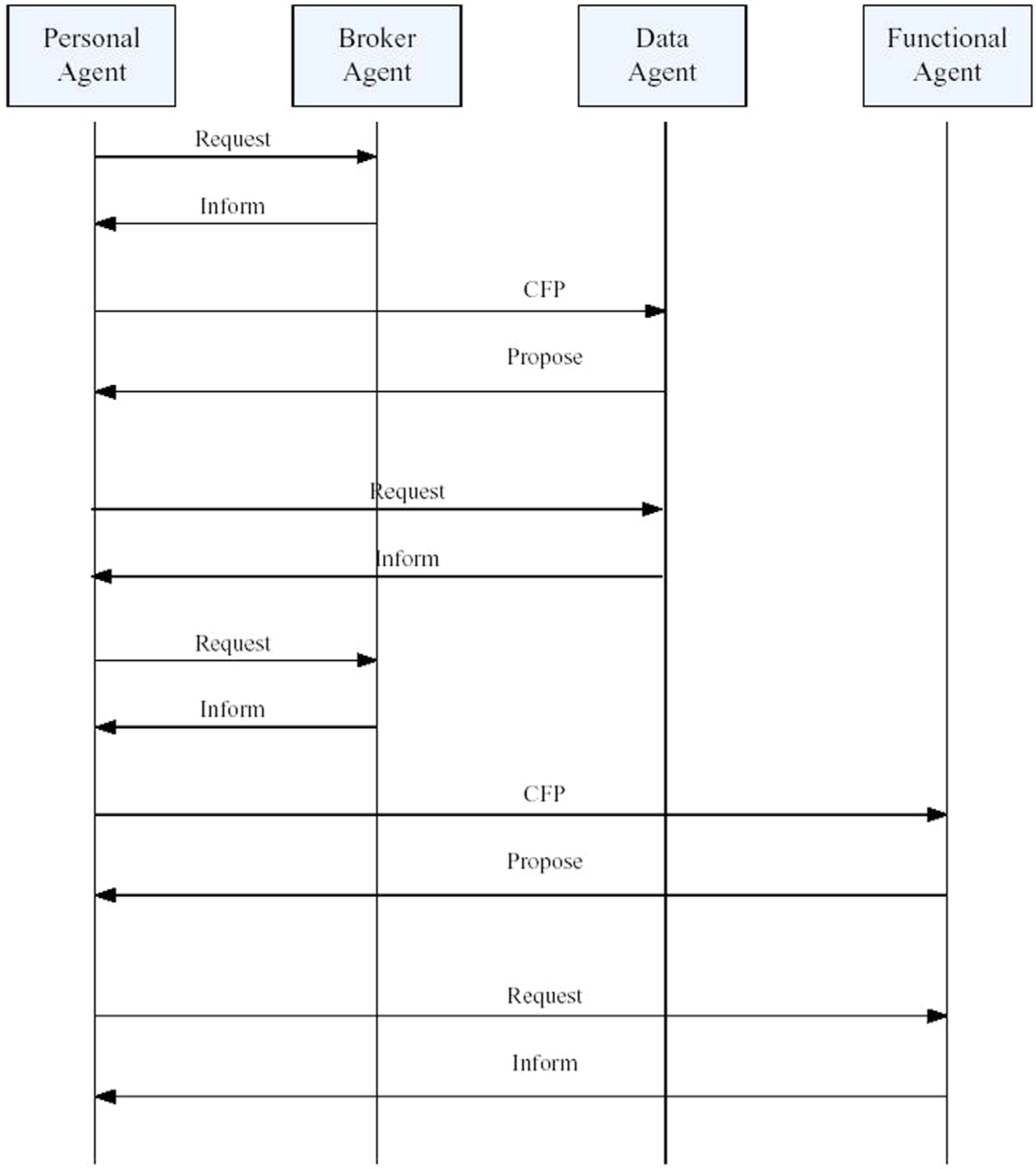

Fig. 7. Agent communication sequence.

analysis instead of mastering image processing algorithm, software, and tools.

(3) Apply ontology to facilitate semantic enriched Web services can provide better request-service matching. Service matching performed by Broker Agent along with ontology can assure the correctness of matching service requester and service provider. In other words, the capabilities offered by agents to query and invoke semantically enriched Web services is based on enhanced registries enriched with semantic information that provide semantic matching to service queries and published service descriptions.

(4) New services, agents, and users can be easily added to the framework, thus providing an extendable and flexible open system.

5. Conclusion

In this study, we present a framework that provides easy access to heterogeneous data sources and image processing algorithms through ontology and multi-agent Systems; meanwhile, we also exploit the capabilities offered by multi-agent systems to query and invoke semantically enriched Web services. All the users, data sources and algorithms are represented by different types of agents. Service providers register themselves to the yellow page service provided by broker agents with semantic information. PA represent users and send user's requests to broker agents. Broker agent then performs semantic matching in between services registered within yellow page services and service request submitted by Personal Agent. The advantages of

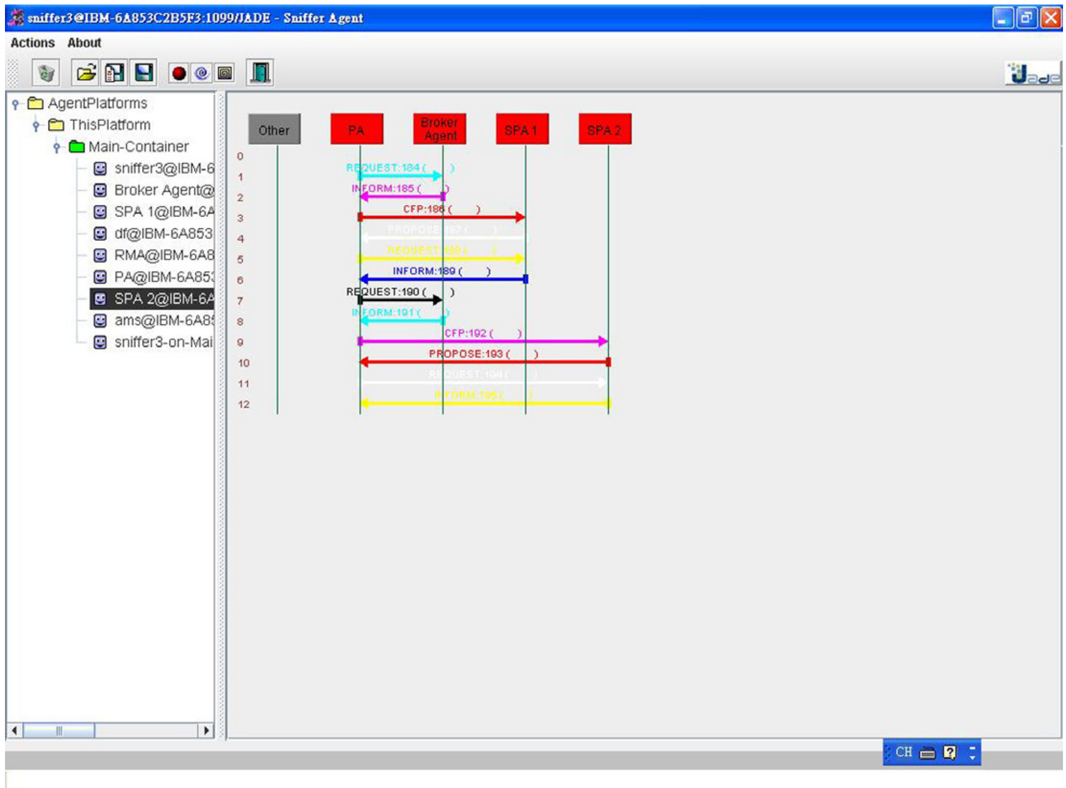

Fig. 8. Snapshot of agent communication sequence in JADE.

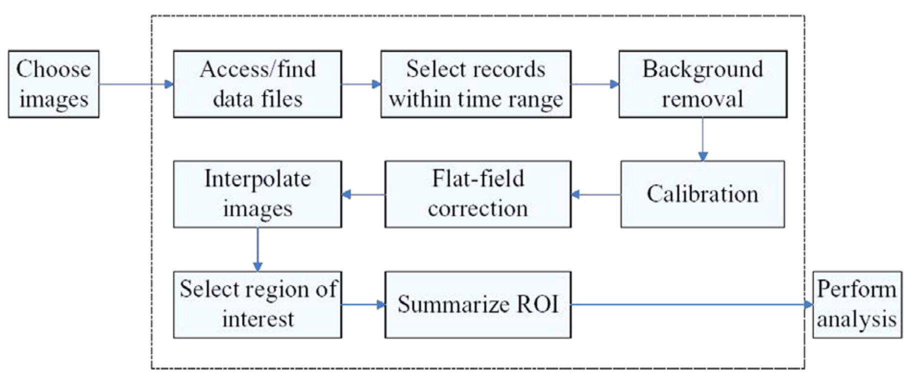

Fig. 9. Illustration example workflow.

the proposed framework can be summarized as follows: (1) develop ontology which includes standardized, community-accepted descriptions for the auroral images. (2) Auroral scientists can focus on their research instead of mastering image processing algorithm, software, tools. (3) Users may invoke a set of Web services with the integration of Web services and intelligent agents. This generates the foreseeable benefits of connecting these two application domains, once the interconnection is established, intelligent agent concepts and technologies will help enable new, advanced operational and usage modes of Web services. (4) Provide an environment which is easy to obtain and share research data and image processing algorithms with the assistance of ontology and multi-agent systems. (5) New services, agents, users and service registries can be easily added to the framework, thus providing an expandable and flexible open system. The framework could easily be extended for similar domains, such as other satellite images and Earth Sciences. The prototype implementation indicates that the proposed framework is flexible, robust and extendable.

References

Bailin, S. C., & Truszkowski, W. (2001) Ontology negotiation between scientific archives. In *2001 Proceedings of thirteenth international conference on scientific and statistical database management* (pp. 245–250). Virginia.

Baousis, V., Zavitsanos, E., Spiliopoulos, V., Hadjiefthymiades, S., Merakos, L., & Veronis, G. (2006) Wireless web services using mobile agents and ontologies. In *2006 ACS/IEEE international conference on pervasive services* (pp. 69–77). Beijing.

Bravo, M. C., Perez, J., Sosa, V. J., Montes, A., & Reyes, G. (2005) Ontology support for communicating agents in negotiation processes. In *2005 Fifth international conference on hybrid intelligent systems* (pp. 482–487). Rio de Janeiro.

Chen, R., Chen, D., & Lin, S. (2005). ACTAM: Cooperative multi-agent system architecture for urban traffic signal control. *IEICE Transactions on Information and Systems, E88-D*(1), 119–126.

Day, M., Lu, C., Yang, J., Chiou, G., Ong, C., & Hsu, W. (2005) Designing an ontology-based intelligent tutoring agent with instant messaging. In *ICALT 2005 fifth IEEE international conference on advanced learning technologies* (pp. 318–320). Kaohsiung.

Djorgovski, S. G. (2005) Virtual astronomy, information technology, and the new scientific methodology. In *Proceedings of seventh international workshop on computer architecture for machine perception, CAMP* (pp. 125–132). Terrasini-Palermo.

Fonseca, F., Egenhofer, M., Agouris, P., & Camara, C. (2002). Using ontologies for integrated geographic information systems. *Transactions in GIS, 6*(3), 231–258.

Huhns, M. N., & Singh, M. P. (1997). Ontologies for agents. *Internet Computing, IEEE*(6), 81–83.

JADE, http://jade.tilab.com/.

Jennings, N. R., & Wooldridge, M. J. (1998). Applications of intelligent agents. In *Agent technologies: Foundations, applications, and markets* (pp. 3–28). Springer.

Jing, D., Bi, S., & Wu, F. (2005) Geospatial information services on the basis of agent and OWL-S. In *Proceedings of 2005 IEEE international geoscience and remote sensing symposium, IGARSS '05* (pp. 885–888). Seoul.

Lee, K., Yun, J., & Jo, G. (2003). MoCAAS: Auction agent system using a collaborative mobile agent in electronic commerce. *Expert Systems with Applications, 24*, 183–187.

Malucelli, A., Palzer, D., & Oliveira, E. (2005) Combining ontologies and agents to help in solving the heterogeneity problem in e-commerce negotiations. In *Proceedings of international workshop on data engineering issues in e-commerce* (pp. 26–35). Tokyo.

Obitko, M., & Marik, V. (2002) Ontologies for multi-agent systems in manufacturing domain. In *Proceedings of 13th international workshop on database and expert systems applications* (pp. 597–602). Aix-en-Provence.

Ohishi, M., Mizumoto, Y., Yasuda, N., Shirasaki, Y., Tanaka, M., Honda, S., & Masunaga, Y. (2004) A prototype toward Japanese virtual observatory (JVO). In *2004 International symposium on applications and the internet workshops* (pp. 591–595). Tokyo.

Schlenoff, C., Washington, R., & Barbera, T. (2005) An intelligent ground vehicle ontology to enable multi-agent system integration. In *International conference on integration of knowledge intensive multi-agent systems* (pp. 169–174) Waltham.

Soo, V., Lee, C., Yeh, J., & Chen, C. (2002) Using sharable ontology to retrieve historical images. In *Proceedings of the 2nd ACM/IEEE-CS joint conference on digital libraries* (pp. 197–198). Portland.

Soo, V., Lin, S. Yang, S., Lin, S., & Cheng, S. (2005) A cooperative multi-agent platform for invention based on ontology and patent document analysis. In *Proceedings of the ninth international conference on computer supported cooperative work in design* (pp. 411–416).

W3C, Web Services Architecture, http://www.w3.org/TR/2004/NOTE-ws-arch-20040211/, 2004.

Wu, Z., He, Y., & Jin, H. (2005) A model of intelligent distributed medical diagnosis and therapy system based on mobile agent and ontology. In *Proceedings of eighth international conference on high-performance computing in Asia-Pacific region* (pp. 582–587). Beijing.