Grid Workflow Validation Using Ontology-Based Tacit Knowledge: A Case Study for Quantitative Remote Sensing Applications

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Abstract: Workflow for remote sensing quantitative retrieval is the "bridge" between Grid services and Grid-enabled application of remote sensing quantitative retrieval. Workflow averts low-level implementation details of the Grid and hence enables users to focus on higher levels of application. The workflow for remote sensing quantitative retrieval plays an important role in remote sensing Grid and Cloud computing services, which can support the modelling, construction and implementation of large-scale complicated applications of remote sensing science. The validation of workflow is important in order to support the large-scale sophisticated scientific computation processes with enhanced performance and to minimize potential waste of time and resources. To research the semantic correctness of user-defined workflows, in this paper, we propose a workflow validation method based on tacit knowledge research in the remote sensing domain. We first discuss the remote sensing model and metadata. Through detailed analysis, we then discuss the method of extracting the domain tacit

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Sensitivity: Internal

knowledge and expressing the knowledge with ontology. Additionally, we construct the domain ontology with Protégé. Through our experimental study, we verify the validity of this method in two ways, namely data source consistency error validation and parameters matching error validation.

Key word: Workflow, validation, ontology, tacit knowledge

1 Introduction

Quantitative remote sensing is becoming increasingly computation-intensive. Problem-solving related to quantitative remote sensing usually involves the invocation of a number and variety of analysis steps or procedures. However, these can typically be invoked in a routine manner. It is no longer possible for scientists to carry out their day-to-day activities without heavy use of computing. Remote sensing quantitative retrieval, focusing on modelling and algorithms, has accumulated plenty of models and algorithms in recent decades. Some of them have become the standard methods for most applications. On the other hand, due to multiple data resources and study requirements, many new algorithms have sprung up. Some of them are just reinventions of existing work (especially pre-processing models), which highlights resource redundancy that goes against the original intention of sharing (Dong et al. 2013). It is necessary to share models for remote sensing quantitative retrieval to help users choose the best among multiple models employing different mathematics, to avoid misuse of models, to reduce resource-wasting for rebuilding existing models, and to provide a reference for researchers to study models that have not been developed yet in the application fields.

Scientific workflows are widely recognised as a “useful paradigm to describe, manage, and share complex scientific analyses”. In a Grid architecture, a grid workflow management system is a type of high-level grid middleware which is supposed to support modelling, redesign and execution of large-scale sophisticated scientific and business processes in many complex e-science and e-business applications (Chen and Yang, 2006, 2008). The use of workflows allows offloading much of the data processing to remote components and makes it feasible to execute even larger and more complex workflows on regular personal computers. A further advantage of using workflows is the potential to automate the highly repetitive processing stages that research work often involves. This, in turn, can stimulate the pace of research and the overall productivity of experimentation through evident savings in time and effort. With scientific workflow systems, distributed scientists can collaborate on conducting large-scale scientific experiments and knowledge discovery applications using distributed systems of computing resources, datasets, and devices.

Workflow for remote sensing quantitative retrieval bridges Grid services and Grid-enabled application of remote sensing quantitative retrieval. Workflow integrates distributed data, algorithms and components, and heterogeneous resources of distributed computing clusters in a more friendly and effective way into a Grid computing environment (Yu and Buyya, 2005). It avoids low-level implementation details of the Grid, and hence, users can focus on higher levels of application (Ai et al., 2010). To ensure an efficient support for the large-scale complicated remote sensing application business process, we must verify the correctness of the Grid workflow description and execution. Validation failure results in faults or flaws in the Grid workflow description and execution. If the grid workflow restarts frequently, this will cause an enormous waste of resources and time, especially in Grid workflow involving many distributed resources. Therefore, validation in Grid workflow is very important.

However, despite the importance of Grid workflow validation, current research in this area is still in its preliminary stage. Many existing grid workflow tools do not provide integrated visual workflow composition environments and/or do not have workflow validation mechanisms to ensure structural and semantic correctness of composed grid workflows (Zhang 2006). In the existing research, some significant work has been performed focusing on the issue of Grid workflow validation. Van der Aalst (1998) and Adam et al. (1998) discussed how to use Petri Net to simulate and analyse workflow processes. Van der Aalst and Van Hee (2004) analysed the structure errors in workflows based on Petri Net and computed the performance parameters using a simulation method. Li et al., (2004) and Li and Yang (2005) proposed some validation algorithms through the analysis of resource constraints in the workflow description and execution. Marjanovic and Orlowska (1999) proposed some validation methods to examine the consistency of temporal constraints by assigning maximum and minimum durations to each activity. Sadiq and Orlowska (2000) proposed a method to analyse workflow process models based on graph reduction techniques. Chen and Yang (2005, 2007) discussed dependency and its impact on the temporal validation of temporal effectiveness and efficiency in Grid workflow systems.

Current research in this area is more concerned with the syntactic structure and resource constraint validation. However, semantic structure validation is also very important. In this paper, we propose a method based on tacit knowledge for remote sensing quantitative retrieval Grid workflow validation. We first discuss the remote sensing domain standards and expert experience knowledge (a type of tacit knowledge). We then extract a type of experience tacit knowledge in a proposed method and express it with ontology for workflow validation.

The remainder of the paper is organized as follows. Section 2 discusses the related work. Section 3 presents our research framework and method. Section 4 outlines our experimental study and discusses the results. Section 5 concludes our contributions and suggests some future work.

2 Related research works

The original idea of ontology derives from exploring the being and existence, as well as the basic categories of being and their relationships (http://en.wikipedia.org/wiki/Ontology). Choi et al. (2006) classified ontology into three categories: Global Ontology, Local Ontology, and Domain Ontology. In this paper, a remote sensing domain ontology will be constructed. Web Ontology Language (OWL) is a standard framework proposed by W3C (Argüello and Des, 2007), which is widely used to describe and express ontology in a formatted way. OWL formally expresses three aspects of ontology: Class, Attribute and Instance. Many tools have been developed by different organizations for constructing ontology, such as Protégé (http://protege.stanford.edu/), WebOnto (http://projects.kmi.open.ac.uk/webonto/), and WebODE (http://mayor2.dia.fi.upm.es/60-webode). In this paper, Protégé is used to construct the remote sensing domain ontology.

Tacit knowledge is a type of knowledge that exists in one's mind, in a particular environment, which is often difficult to formalize and communicate. It is the key factor of knowledge innovation (Polanyi, 1996). Tacit knowledge acquisition refers to the extraction of the implicit knowledge from the external knowledge source and representation of the knowledge with a suitable knowledge expression approach for sharing and exchanging in an organization. Since the concept of tacit knowledge was proposed by Polanyi, many scholars have researched tacit knowledge acquisition and the transformation between tacit knowledge and explicit knowledge. From different perspectives such as management, cognitive psychology, and engineering, a series of methods and models have also been proposed.

Nonaka et al. (2000) proposed the SECI model as well as the "field" theory from the perspective of management, which laid the foundation for tacit knowledge acquisition and the transformation. Drucker (1995) thought that tacit knowledge (such as some type of special skill) could not be explained in words and that its existence could only be proven through demonstration. Therefore, the only way to learn tacit knowledge was through practice and realization. Koskinen and Vanharanta (2002) thought that we should acquire tacit knowledge using the action learning method and face-to-face informal communication. In general, from the management science perspective, tacit knowledge acquisition methods are direct, with a focus on observation, experience and comprehension. This method is suitable for acquiring skilled tacit knowledge that is difficult to describe using language.

Sternberg et al. (2000) discussed the relationship of tacit knowledge, the human mind and psychological processes from the psychological perspective. They thought that tacit knowledge acquisition generally did not require the help of others; it could prompt the individual to realize the value of pursuing goals and have an important role in real life. Sun et al. (2005) suggested an integration model of skill learning, considering the implicit and explicit learning process and revealing the details of the interaction between different learning models. Tacit knowledge research in psychology has focused on individual cognitive psychology and psychological mode. The views were that tacit knowledge acquisition was mainly realized through learning and that different cognition and learning models produced different effects.

Noh et al. (2000) proposed a method based on the case. Through reasoning and examination of an expert's cognitive map, one could extract the implicit knowledge of experts. Abidi et al. (2005) proposed a type of medical model of tacit knowledge including four parts: unit situation, situation architecture, medical plot and health event. It provided a method of three phases for medical experts' tacit knowledge acquisition and its computer realization. Chen (2010) developed a tacit knowledge representation and reasoning method based on ontology, which adopted the web ontology language to express experience tacit knowledge in a structured manner. Charlin et al. (2012) researched the clinical reasoning with tacit knowledge in medical practice, which unravels the complexity through graphical representation. Senthil (2013) used tacit knowledge representation for product design and described the evolution, challenges and future of knowledge representation in product design. From the engineering perspective of the tacit knowledge acquisition study, researchers worked on different applications of tacit knowledge in the field of formalization description and modelling analysis and the algorithm for implementation.

3 The research framework

The research framework proposed in this paper consists of three major parts: the remote sensing domain experts, the knowledge system and the Grid workflow platform. The architecture of the research framework is shown in Figure 1.

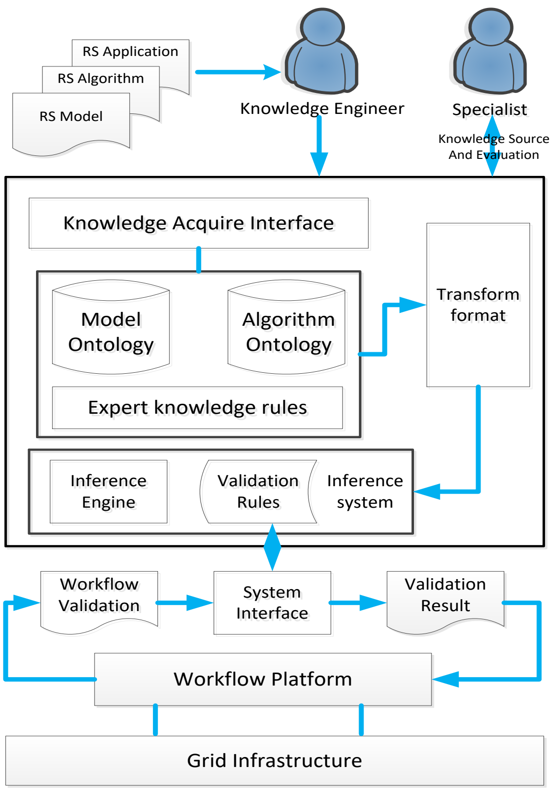

Figure 1. The architecture of the framework.

The remote sensing domain experts are the source of knowledge from which we can gain domain concepts and knowledge rules. They also evaluate the existing knowledge. The knowledge system contains knowledge acquisition, representation, transformation and inference. Representation involves representing and encoding domain concepts and knowledge in a computer-readable format. Inference involves judging the correctness of the workflow by the knowledge rules obtained from domain experts.

It is a core component of the framework. The Grid workflow is the representation and application platform of the framework. The sequence diagram of the framework processing logic is shown in Figure 2.

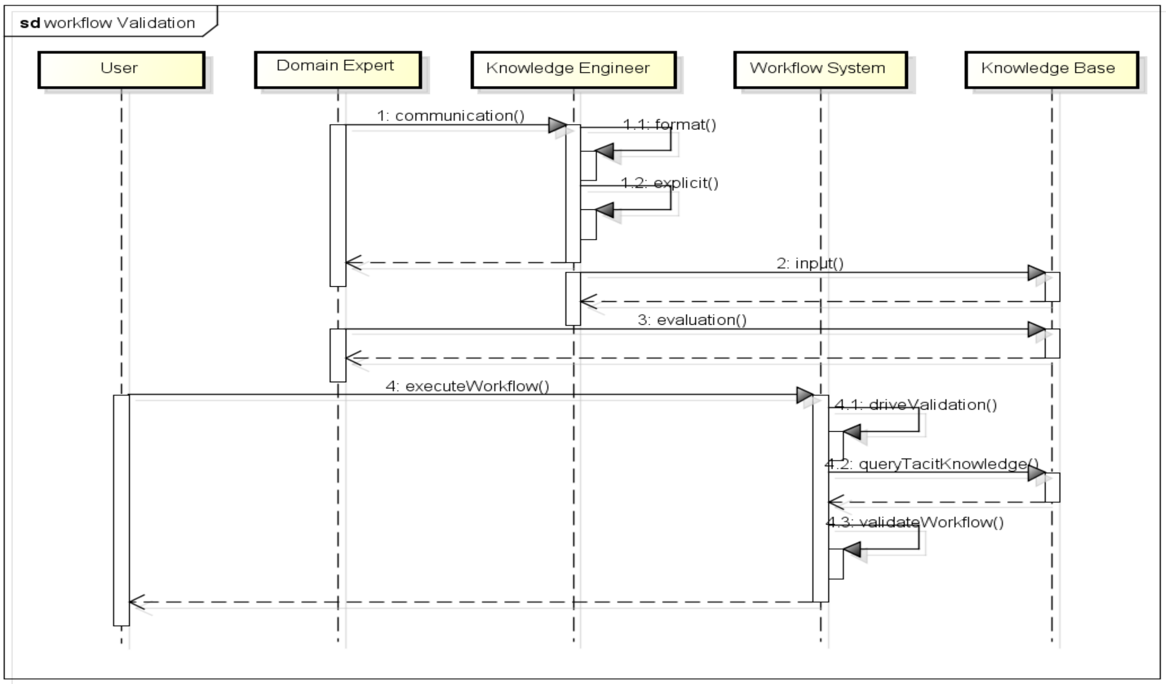

Figure 2. The sequence diagram of the framework processing logic.

3.1 Remote sensing model metadata reference

Metadata is usually defined as "data about data". Remote sensing model metadata standards and specifications are the basis for model information sharing, as well as indicating the level of technology development. Additionally, many researchers have conducted very meaningful work on metadata, and some metadata standards have been defined (https://www.fgdc.gov/metadata). However, there is no unified standard for geoscience metadata (metadata for geoscience research and resource sharing) because the definition and design of metadata itself is a process of knowledge accumulation and structured expression. It requires knowledge accumulation and constant improvement over a long period of time. In this paper, from the perspective of model validation, we design a set of remote sensing model metadata reference frameworks in the area of aerosol retrieval. The static UML structure diagram is given in Figure 3.

In Figure 3, we divide remote sensing model metadata into seven major categories: MD_identifier class, MD_parameter class, MD_manageInfo class, MD_priciple class, MD_scope class, MD_dataset class and MD_algorithm class. All of these classes have properties that are used for describing and restricting the model. Through these properties, we can obtain relationships between models that can be used in workflow validation.

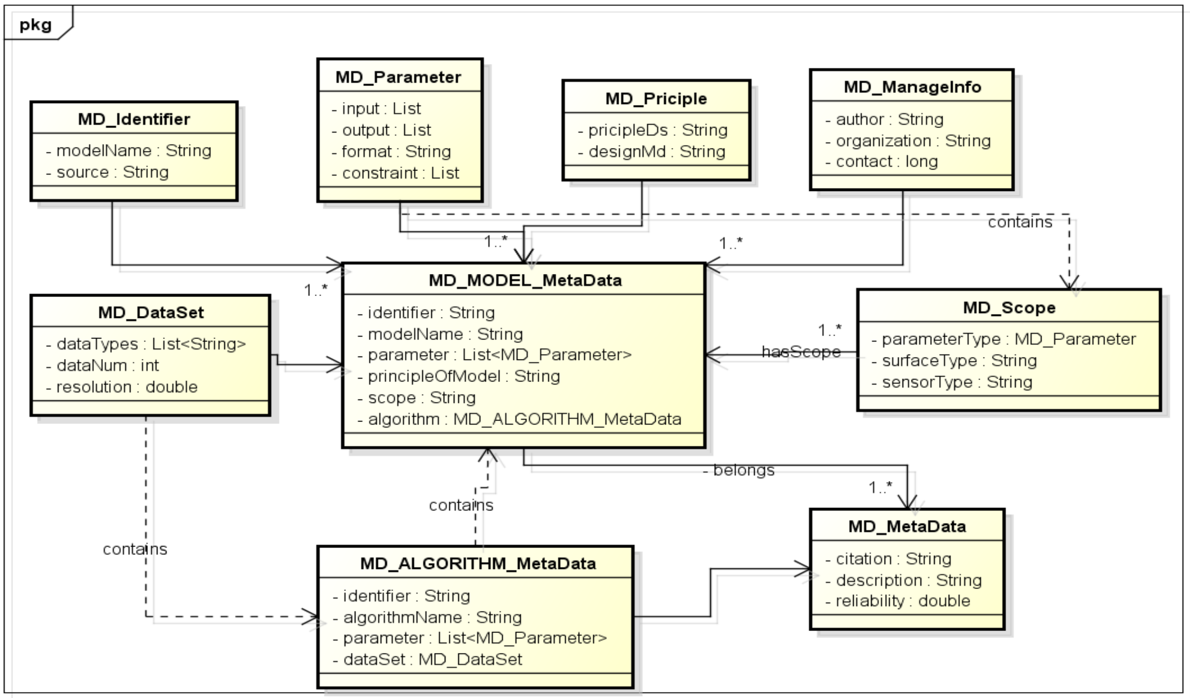

Figure 3. The static UML structure diagram of model metadata.

3.2 Domain tacit knowledge acquisition

The acquisition process of domain tacit knowledge should support the transformation of tacit knowledge into explicit knowledge. This process contains two main steps: (1) Domain Tacit Knowledge Extraction (DTKE) and (2) Domain Tacit Knowledge Classification (DTKC), as shown in Figure 4. DTKE acquisition filters and obtains the domain knowledge. It restricts the boundary and scope of knowledge and captures the description and summary context of concepts. DTKE is also able to capture axiom and domain rules in a certain domain, through the use of rule-expressed language, such as SWRL (http://www.w3.org/Submission/SWRL/).

The other step is Domain Tacit Knowledge Classification. In this step, after the acquisition of tacit knowledge, we should classify the domain concepts and rules into different classes of objects with common properties. In the classification process, the specific classes are identified by their own individual properties but inherit common properties from upper classes. Finally, the collected information, concepts and rules are encoded into machine-readable ontology in OWL language to constitute the domain knowledge base.

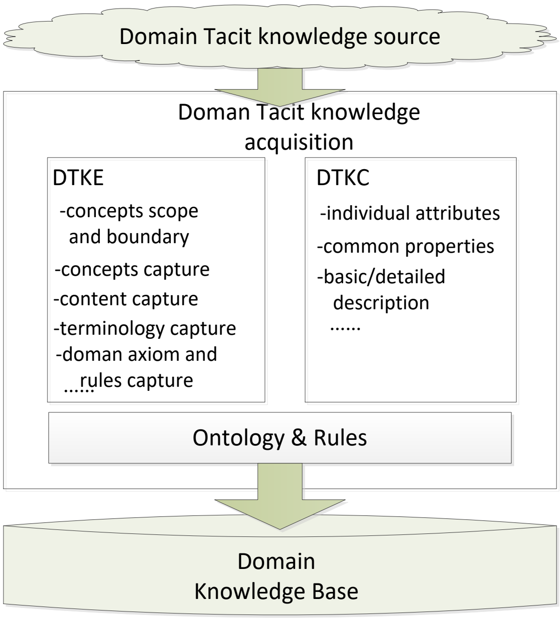

Figure 4. Domain Tacit Knowledge acquisition description.

Tacit knowledge is quite different in each individual. It is often associated with a special field or a specific staff. In general, acquisition methods suitable for all types of tacit knowledge are very difficult to achieve, if not impossible. In this paper, based on the specific type of tacit knowledge and the concrete application of the tacit knowledge, a method of tacit knowledge acquisition and representation is proposed. In this method, a complete tacit knowledge contains at least a problem situation and the core content, as the expression shows: <tacit knowledge> = <problem situation, core content>. The problem situation is the problem domain, such as remote sensing workflow validation in this paper, while the core content contains the solution and result.

We take the quantitative remote sensing aerosol retrieval as the problem situation. We take as an example an aerosol remote sensing retrieval workflow SRAP (Synergic Retrieval of Aerosol Properties) (see Figure 5) to explain the acquisition and expression of expert-indicated tacit knowledge (Xue et al. 2014). We discuss below the acquisition and representation of expert-indicated tacit knowledge in two aspects: data source consistency and parameter matching logic consistency.

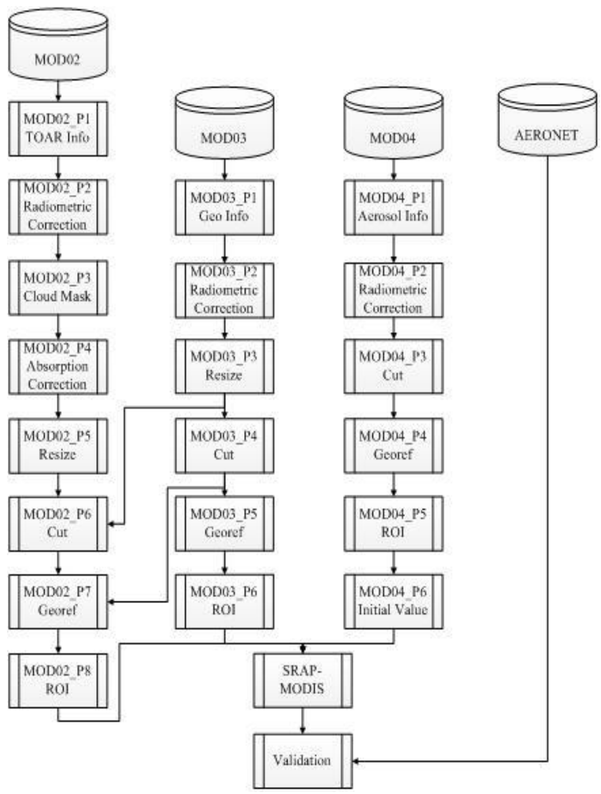

Figure 5. The SRAP workflow (an aerosol remote sensing retrieval workflow) (Xue et al. 2014).

3.2.1 Data source consistency experience rules

The definition of the model data source in the remote sensing quantitative retrieval model ontology element set is divided into two levels: sensors and dataset (or product). According to the remote sensing domain knowledge, the sensor information restricts the applicability of the model. The dataset information must agree with the model input dataset categories. To express the data source information, we give a definition of the data source as follows:

WFData={(SensorType, “TypeName1”,……), (DataSet, “dataset1, dataset2, dataset3, ……”)}.

Specifically, in the SRAP workflow, the data source is defined as follows:

SRAPData={(SensorType, “MODIS”), (DataSet, “mod01, mod02, mod03”)}.

That is, in the SRAP workflow, the sensor type is MODIS, and the dataset contains mod01, mod02 and mod03. In the model metadata description, its expression is as follows:

SensorType = MODIS;

DataSetNum = 3;

DataSet= mod02, mod03, mod04.

3.2.2 Parameter matching experience rules

Parameter matching in this paper is to validate that all input parameters of the current model are in accordance with the output parameters of the precursor models. For example, the current model is P. Its input parameter collection is N. The precursor models of P are A, B and C. The corresponding output parameters collection is M, which is defined as $M=\{A(output)\cup B(output)\cup C(output)\}$. In this situation, if $N\subseteq M$, we can assert that the parameter matching is right. On the contrary, it is asserted that the precursor models cannot meet the requirement of the model input interface. Based on the definition above, we acquire the parameters (Table 1) from the domain expert in the SRAP workflow for its parameter matching validation.

	Terra	Aqua
MOD02	apparent reflectance	apparent reflectance
MOD03	Azimuth sensor solar zenith angle	Azimuth sensor solar zenith angle
MOD04	initial Beta	initial Alpha initial Beta

Table 1. The parameters required of SRAP

According to the definition and discussion above, we acquire the domain expert tacit experience knowledge as validation rules. Here, we formulate two rules as follows:

Rule 1: In the SRAP workflow validation, the input dataset types and number of models must be the same as the workflow data source. Otherwise, the data source is not consistent.

Rule 2: In the SRAP workflow validation, the input parameters set of the current model must be a subset of the intersection of all its precursor models' output parameter sets. Otherwise, the parameters do not match.

In the two rules, "SRAP workflow validation" is the problem situation, and the others are core contents, including the decision method and conclusion. In the next section, we will discuss how to construct a remote sensing model ontology and how to express the tacit knowledge by ontology.

3.3 Remote sensing model (RSModel) domain ontology

In this paper, Protégé is used to construct RSModel domain ontology to represent the remote sensing domain concepts, rules and the relations between domain concepts.

Figure 6 shows the pre-processing of remote sensing domain expert experience knowledge, which is divided into two sub-processing phases:

1). Remote sensing information acquisition: The information includes the RSModel metadata and algorithm metadata described above. Additionally, we extract the relationships between the models.

2). Constructing remote sensing model structured knowledge ontology with Protégé: In our preliminary experiment, we use Protégé to build the RSModel ontology. The OWL formatted language is adopted to encode remote sensing model ontology. The classes of RSModel, attributes of RSModel class, and contents of RSModel properties are well-described and set up to construct the relevant knowledge of the aerosol retrieval RSModel.

In the experimental framework, the process of the RSModel knowledge ontology construction is outlined as follows:

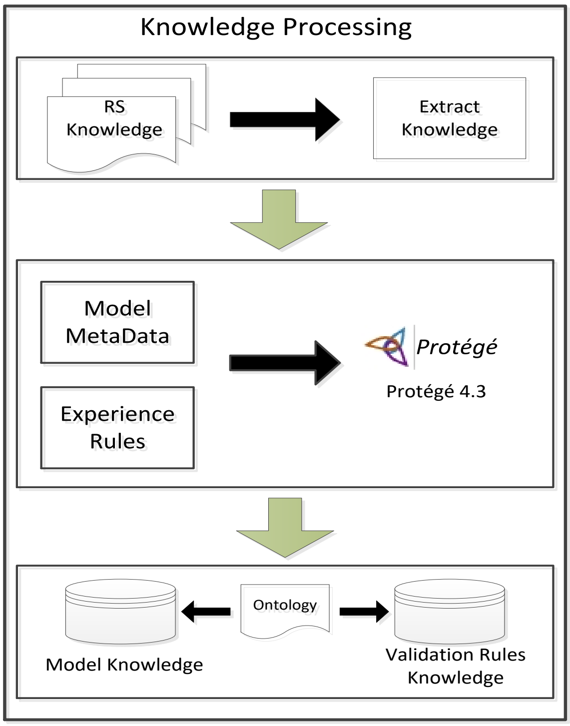

Figure 6. The processing steps of domain knowledge.

1). RSModel knowledge: RSModel knowledge is mainly from RSModel metadata. RSModel metadata is divided into seven major described classes, including the MD_identifier class, MD_parameter class, MD_priciple class, MD_manageInfo class, MD_scope class, MD_dataset class, and MD_algorithm class. Sub-classes include model name, dataType, dataNum, and so on.

2). Expert experience tacit knowledge: The expert experience tacit knowledge is mainly used as the constraints of the RSModel. The expert experience tacit knowledge is divided into three major classes, including the relationship of the RSModel, the data source restrictions and the input/output parameters between the RSModels.

Figure 7 is the aerosol retrieval RSModel ontology built in Protégé. The left frame shows RSModel metadata knowledge, and the class of restraint that contains the remote sensing domain expert tacit knowledge described above is assigned in the right frame.

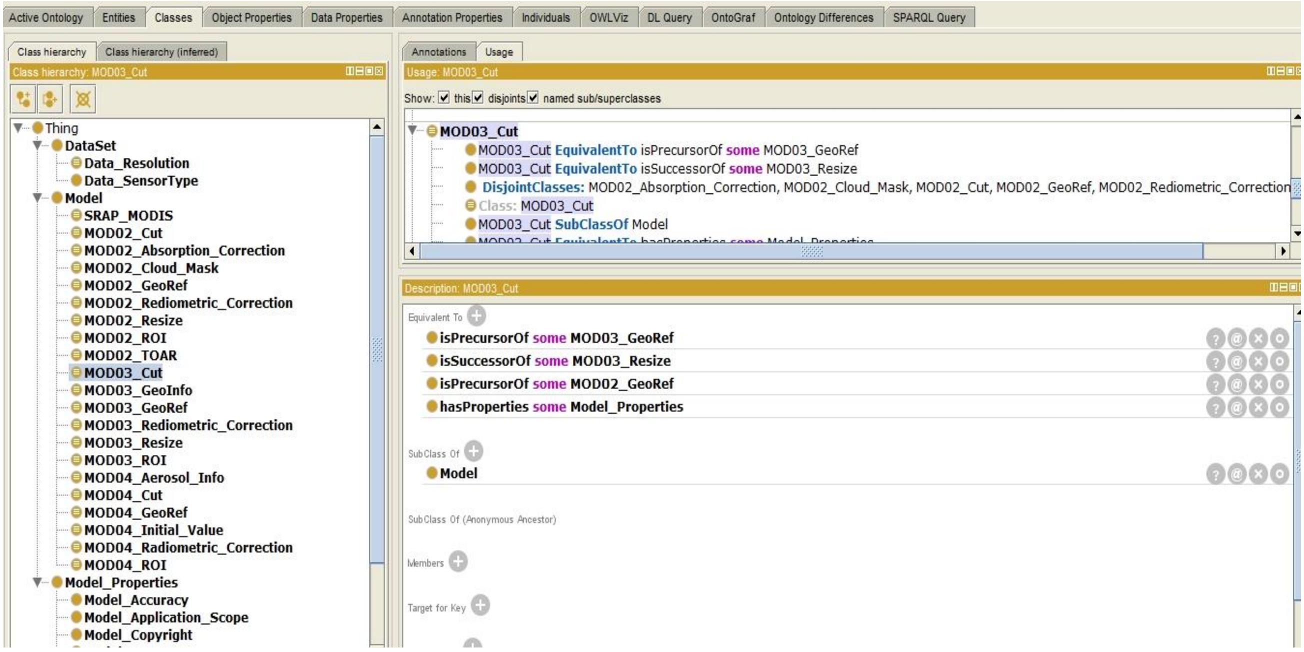

Figure 7. The aerosol retrieval RSModel ontology created by Protégé.

4 Experiments and discussion

Based on the above discussion of model metadata, ontology, and tacit knowledge, we have conducted some experiments on the Grid workflow platform (Figure 8) constructed by the TeleGeoProcessing research group of the Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences. In this Grid workflow platform, we can consult a remote sensing model in the model list view. The model can be dragged into the canvas on the right side of Figure 8 to construct a workflow. Then, we can submit the workflow into grid platform to execute it. In this paper, we just add a workflow validation functionality into the platform. In this experiment, taking the SRAP workflow as an example, we validate the validity of the method discussed above from the viewpoint of data source consistency and parameter matching consistency. First, we obtain remote sensing domain concepts and knowledge from remote sensing domain experts by the method described in Section 3.2. Then, we construct the domain ontology and rules knowledge described above in Protégé for the workflow validation knowledge base. When we validate the correctness of the workflow, we retrieve knowledge from the knowledge base for judgement. The validation process is shown in Figure 9. In the process, we first get the input datasets and parameters of every model. Then, we establish a link relationship table of models. Then, we execute the SRAP workflow validation from four aspects: model info consistency, sensor info consistency, data source consistency, and parameter consistency in every model with the knowledge inference in the system.

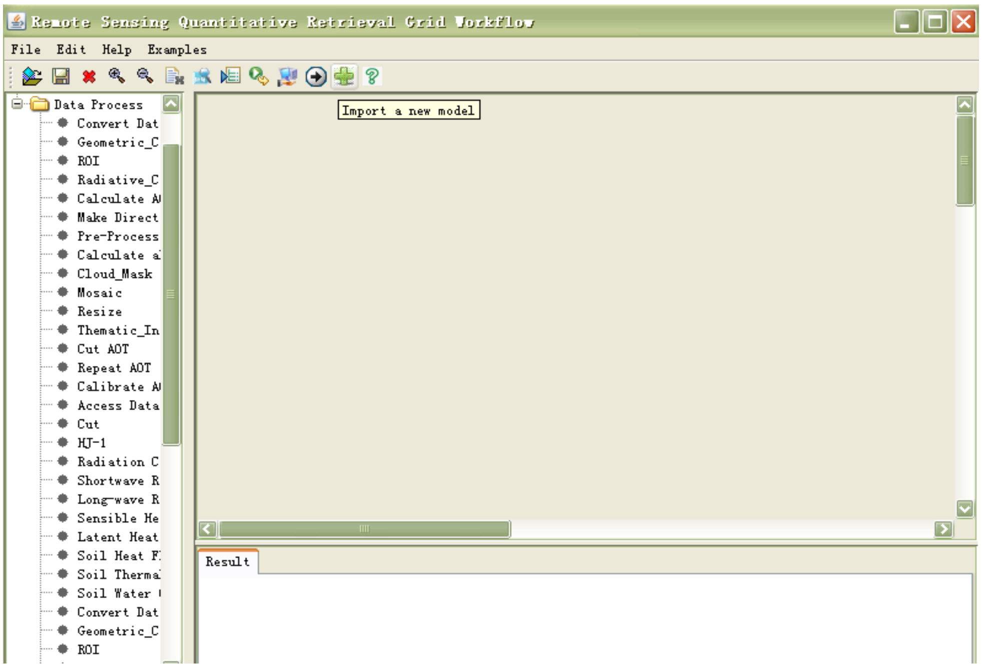

Figure 8. Grid workflow visualized composition tool for remote sensing quantitative retrieval.

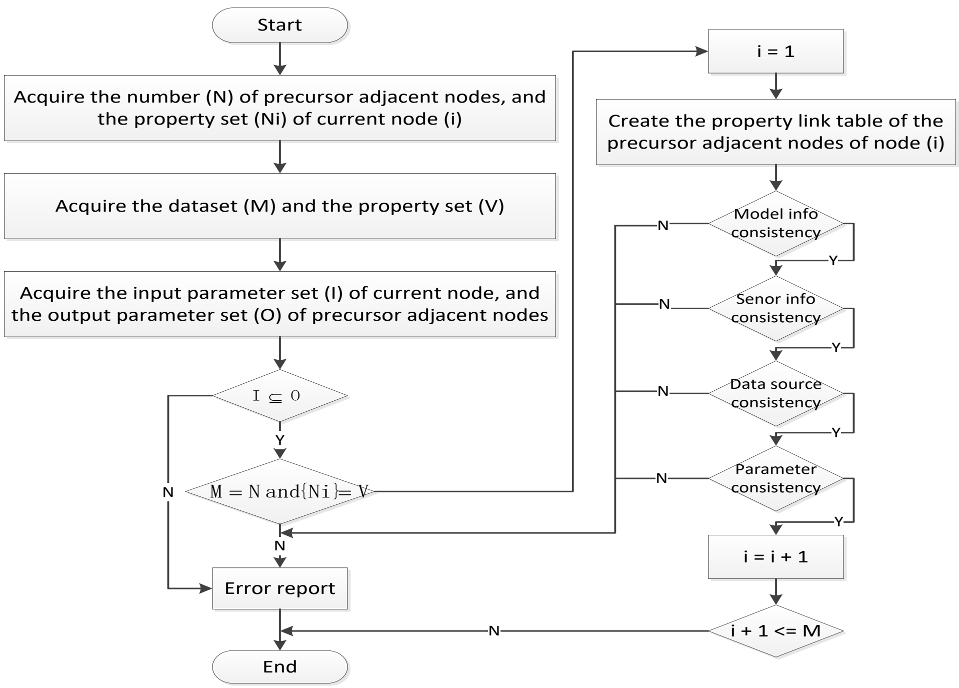

Figure 9. The validation process flow diagram.

4.1 Data source consistency error validation

Data source consistency error is divided into two sets of circumstances: one is that the calculation model lacks a data source, leading to computing failure; another set of circumstances is that the data source number is correct, but there are abnormal nodes that do not match the data with the correct data source requirements. Both of these circumstances violate the rules described in Section 3.2.1, which are encoded in knowledge base. Figure 10 shows the circumstance of lacking a data source. According to the semantic description of the SRAP workflow discussed above, there should be three datasets in the data source. However, in this workflow, there are only two datasets (mod03 and mod04). So in the process of validation, we see a warning tip: “lack of data source: mod02”. In Figure 11, although there are three branching processes of three datasets, in the branching process of mod02, all the process model is adapted for the mod02 dataset except the “Thematic_Information” model, which is adapted for the mod03 dataset. In the process of workflow validation, the model after “Thematic_Information” cannot read the right mod02 dataset. So the system gives the warning tips: “Thematic_Information model’s dataset not correct, it should be mod02”. From the experiment, we can see that this method is capable of not only identifying the errors in the workflow but also indicating which model is incorrect and giving the appropriate warning message.

4.2 Parameter matching error validation

As mentioned in Section 3 above, there are input parameters in the SRAP workflow: the all-day apparent reflectance of mod02, the all-day apparent reflectance of mod03, sensor zenith angle, solar zenith angle, and the all-day alpha and beta initial value of mod04.

In the branching process of mod04 calculation, the output parameters of the initial value calculation model should be alpha (TERRA) and beta (TERRA and AQUA), which are the rules encoded in the knowledge base. In our experiments, we designed a workflow in which the output parameters of the initial value calculation model have only alpha. In this workflow, although the data source is consistent and the process logic is suitable for SRAP workflow semantic correctness, the input parameters for the “Calculate AOD” model cannot be met from the output parameters of its precursor model in the parameter matching process by rules reasoning. Using the rules in the knowledge base, the system can tell that the “Calculate AOD” model cannot meet the need of the beta parameter from the precursor models. So in the validation process, the system gives a warning tip: “Calculate AOD is lack of parameters: beta_aqua, beta_terra” (Figure 12).

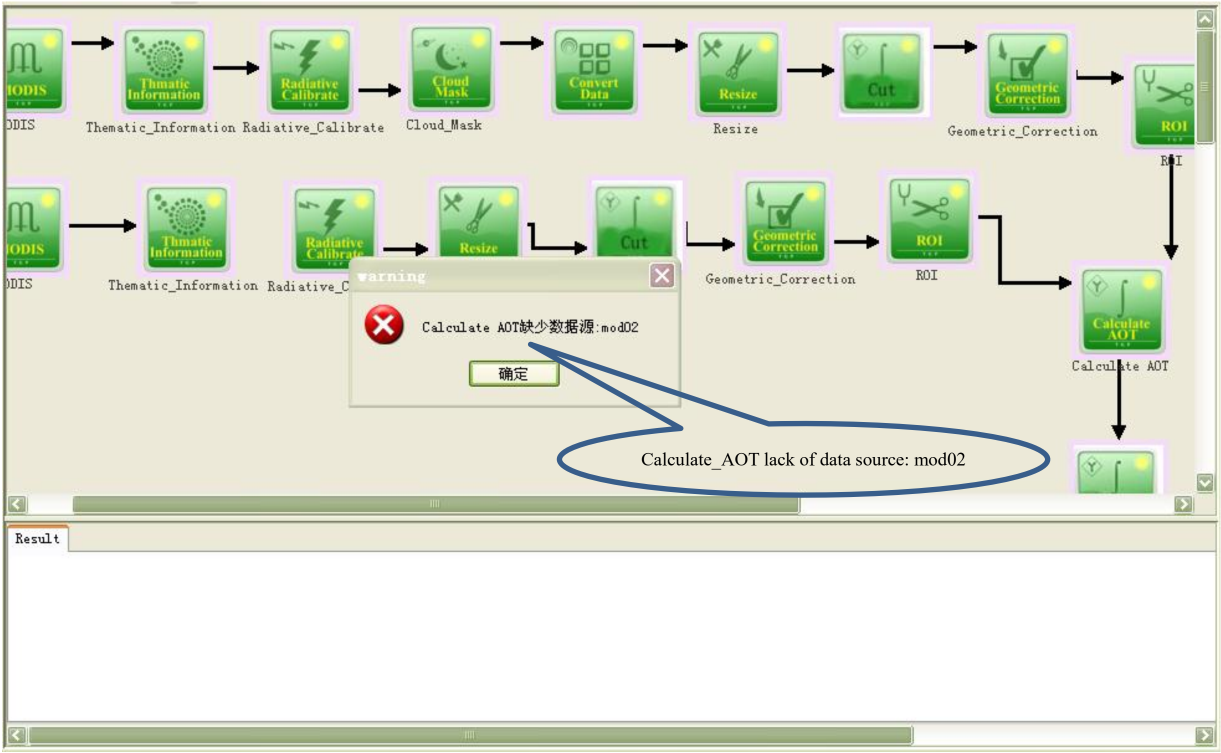

Figure 10. The validation of lack of data (tip: “Calculate_AOT lack of data source: mod02”)

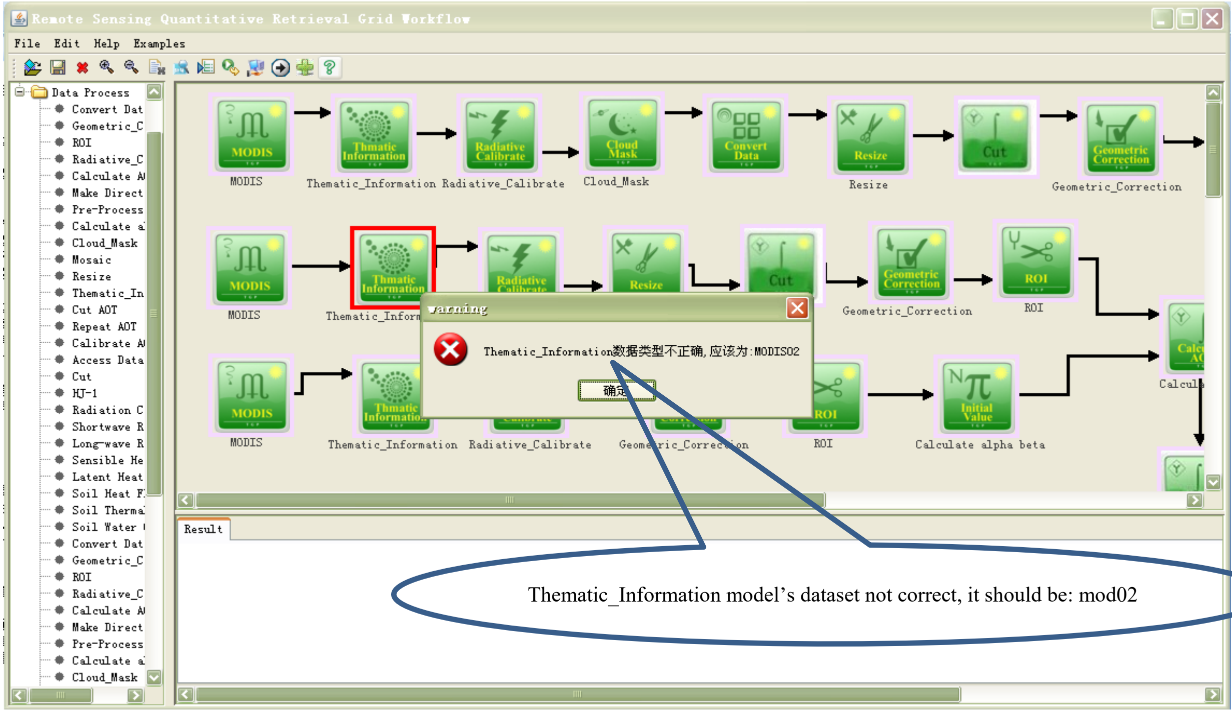

Figure 11. The validation of the wrong data source (tips: "Thematic_Information model's dataset not correct, it should be mod02")

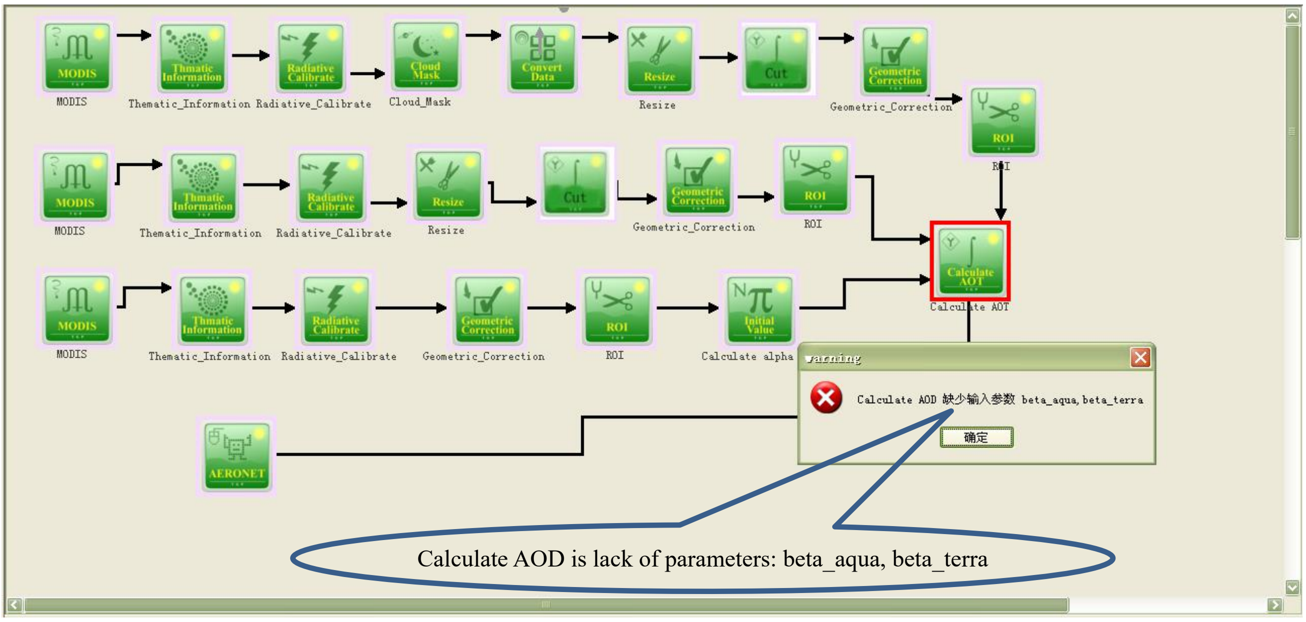

Figure 12. Parameter matching error validation (tip: "Calculate AOD is lack of parameters: beta_aqua, beta_terra")

5. Conclusion and future work

In remote sensing Grid application, the remote sensing quantitative retrieval Grid workflow plays an important role. In the Grid workflow system, the remote sensing Grid services can be gathered together in a friendly way. In this way, without knowing the underlying Grid implementation details or where the services are, the end users could construct the abstract workflow of remote sensing application. To avoid wasting time and resources, the correctness of the Grid workflow is important, especially in the remote sensing quantitative retrieval Grid workflow.

In this paper, through detailed analysis of remote sensing models and metadata and discussion of the tacit knowledge acquisition and representation method, we have constructed the domain ontology with Protégé and propose a Grid workflow validation method based on tacit knowledge research in the remote sensing domain.

As part of future work, we will strengthen the remote sensing model ontology and extract more domain expert experience rules to acquire more tacit knowledge for our system. In addition, we will study and consider other methods of tacit knowledge acquisition and representation to further strengthen our system.

Acknowledgments

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