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Service-oriented model-encapsulation strategy for sharing and integrating heterogeneous geo-analysis models in an open web environment

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ABSTRACT

Earth environment is extremely complicated and constantly changing; thus, it is widely accepted that the use of a single geo-analysis model cannot accurately represent all details when solving complex geo-problems. Over several years of research, numerous geo-analysis models have been developed. However, a collaborative barrier between model providers and model users still exists. The development of cloud computing has provided a new and promising approach for sharing and integrating geo-analysis models across an open web environment. To share and integrate these heterogeneous models, encapsulation studies should be conducted that are aimed at shielding original execution differences to create services which can be reused in the web environment. Although some model service standards (such as Web Processing Service (WPS) and Geo Processing Workflow (GPW)) have been designed and developed to help researchers construct model services, various problems regarding model encapsulation remain. (1) The descriptions of geo-analysis models are complicated and typically require rich-text descriptions and case-study illustrations, which are difficult to fully represent within a single web request (such as the *GetCapabilities* and *DescribeProcess* operations in the WPS standard). (2) Although Web Service technologies can be used to publish model services, model users who want to use a geo-analysis model and copy the model service into another computer still encounter problems (e.g., they cannot access the model deployment dependencies information). This study presents a strategy for encapsulating geo-analysis models to reduce problems encountered when sharing models between model providers and model users and supports the tasks with different web service standards (e.g., the WPS standard). A description method for heterogeneous geo-analysis models is studied. Based on the model description information, the methods for encapsulating the model-execution program to model services and for describing model-service deployment information are also included in the proposed strategy. Hence, the model-description interface, model-execution interface and model-deployment interface are studied to help model providers and model users more easily share, reuse and integrate geo-analysis models in an open web environment. Finally, a prototype system is established, and the WPS standard is employed as an example to verify the capability and practicability of the model-encapsulation strategy. The results show that it is more convenient for modellers to share and integrate heterogeneous geo-analysis models in cloud computing platforms.

1. Introduction

A substantial number of extremely complicated and constantly evolving geo-phenomena and geo-processes occur in Earth's environment (Serreze, 2011; Albanesi and Albanesi, 2014). Geo-analysis models are considered important tools for simulating

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these geo-phenomena and geo-processes (Parsons, 2011; Lin et al., 2013a, 2013b; Sudo et al., 2013). Through years of research, numerous geo-analysis models (on various geo-problems, study areas, spatiotemporal scales) have been built in a variety of disciplines (e.g., Goodchild et al., 1996; Basnyat et al., 2000; Dickinson et al., 2006; Todorova et al., 2010; Dennis et al., 2012; Li et al., 2013, 2015; Zhang et al., 2014, 2015a; Zhu et al., 2015; Yin et al., 2015). However, when simulating synthetic geo-processes and complicated geo-phenomena, the knowledge of a single discipline can hardly address all situations in the environment. The study of sharing and integrating geo-analysis models has been shown as an efficient method to connect researchers across disciplines and to further solve comprehensive geo-problems, especially in interdisciplinary research (Argent, 2004; Argent et al., 2006; Chen et al., 2011; Lin et al., 2015). Sharing and integrating geo-analysis models in an open web environment can also reduce the cost of applying geo-analysis models in practice, thus promoting modelling research (Sancho-Jiménez et al., 2008; Nativi et al., 2013).

To share and integrate heterogeneous geo-analysis models, several problems regarding the heterogeneities of various models must be considered. Because geo-analysis models are developed using different technical approaches by individual researchers or research groups, they are often built on different platforms (e.g., Windows and Linux), coded in different programming languages (e.g., FORTRAN, C/C++, Python) and designed with different user interfaces (e.g., console command line, execution file, dynamic link library). Moreover, it is generally difficult for researchers to understand models from other disciplines. To reduce the heterogeneities of geo-analysis models, encapsulation (also referred to as wrappers in the software development field) studies are necessary.

To date, several model sharing and integration methods have been studied using a variety of theoretical and technological approaches. Some methods are designed to integrate specific models: the coupling of HEC-RAR with MODFLOW to simulate stream-aquifer interactions (Rodriguez et al., 2008); SWAP and MODEFLOW-2000 for modelling groundwater dynamics (Xu et al., 2012); and land-use forecasting models and hydrologic models for improving land-use decision support (McColl and Aggett, 2007). Moreover, a range of frameworks and platforms for sharing and integrating geo-analysis models has been proposed and developed to support dynamic modelling. Examples include the Spatial Modeling Environment (SME) (Maxwell and Costanza, 1997a, 1997b), ModCom (Hillyer et al., 2003), the Open Modeling Interface (OpenMI) (Blind and Gregersen, 2005 and Moore and Tindall, 2005), the European Union's Program for Integrated Earth System Modelling (PRISM) (Valcke et al., 2006), the Common Agricultural Policy Regional Impact modelling system (CAPRI) (Britz et al., 2010), and the Community Surface Dynamics Modeling System (CSDMS) (Peckham and Hutton, 2009). Different modelling frameworks employ various model encapsulation methods. Some frameworks use re-programming (Succar, 2009), while others use input/output data conversion (Pullar and Springer, 2000), and some are based on command calling (Lei et al., 2011).

However, most of these integration frameworks are field specific, and few of these frameworks support the sharing and integration of models over the Internet. Trends in the Internet and in software engineering development over the past 15–20 years have promoted a range of web-based applications that allow users to more easily communicate with each other and access resources. Because geo-analysis models are typically distributed globally and are owned by researchers in multiple disciplines, sharing and integrating geo-analysis models in an open web environment can facilitate the access and use of geo-analysis models (Laniak et al., 2013; Chen et al., 2014). Through this open web environment, model providers can offer their own models, and model users can reuse and integrate these models. Service-oriented Architecture (SOA), which is widely used in the information-sharing and business-processing fields, has been used to integrate model data and geo-analysis models worldwide (Erl, 2008).

Based on the web architecture, the Open GIS Consortium (OGC) has drafted several specifications concerning data and modelling services, such as the Web Mapping Service (WMS), Web Feature Service (WFS), and Web Processing Service (WPS). Based on the WPS standard, much software has been developed to help modellers build model services, such as the PyWPS (Python Web Processing Service), 52°North project and QGIS (Quantum GIS). In addition, Simple Object Access Protocol and Web Service Description Language (SOAP/WSDAL) and 'Model Web' have been studied in terms of the sharing and integration of geo-analysis models (Geller and Turner, 2007). Cloud computing, which is commonly viewed as an efficient method of sharing resources in an open web environment, has also been investigated for geo-analysis modelling services (Wen et al., 2013). Based on these web-based model-services, scientific workflows and business process workflows can be constructed (such as Kepler, WS-BPEL). However, the lack of user control and interactivity during execution appears to limit the application in using model-services (Granell et al., 2013; Zhang et al., 2015b).

Cloud computing can provide massive storage and computational resources for the execution of geo-analysis models. When using a cloud-computing platform, the original model resources are moved from a personal computer to transparent computation servers. Although cloud computing and other web processing architectures provide an open web environment to share resources (model services can also be treated as resources), several existing legacy models cannot be directly uploaded to a server node and used for a model service. The encapsulation work of geo-analysis models is important, and the following difficulties regarding this work are observed.

(1) Heterogeneity of geo-analysis model descriptions. In addition to the execution heterogeneities, substantial variations occur in multi-disciplinary geo-analysis models caused by the different research contexts of disciplines (modellers have difficulties in understanding and employing geo-analysis models of another discipline). A structured model-description method is required to meet the demands of model discovery by model users and model encapsulation by model providers.
(2) Differences between model execution behaviour and web services. Because geo-analysis models typically involve several computation states that partially reflect real geo-processes, model users must act according to the specific requirements in these states. However, the basic architecture of a web service is designed as a simple request–response process, which is in contrast to the execution behaviour of geo-analysis models. Therefore, the description of model execution behaviour that meets the demands of web service architecture should also be considered in model encapsulation.
(3) The deployment information of model-services must be communicated between model providers and model users. In an open web environment, geo-analysis models will be offered and deployed by model providers, and model users employ these models within the same web environment. However, model users who want to use a geo-analysis model and want to copy the model service into another computer still encounter problems (e.g., they cannot access the hardware/software dependencies information). Therefore, model encapsulation should contain sufficient information (flexible and extendable) for modellers from different countries with different research backgrounds.