

Integrated modeling within a Hydrologic Information System: An OpenMI based approach[☆]

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ABSTRACT

This paper presents a prototype software system for integrated environmental modeling that provides interoperability between the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS) and the Open Modeling Interface (OpenMI). The primary motivation for making these two systems interoperable is that the CUAHSI HIS has a primary focus on hydrologic data management and visualization while the OpenMI has a primary focus on integrated environmental modeling. By combining the two systems into a single software application, it is possible to create an integrated environmental modeling environment that scientists and engineers can use to understand and manage environmental systems. Using standards to achieve the steps required to find, gather, integrate, and analyze hydrologic data allows for a wide community of groups to participate because it establishes key rules and protocols that must be followed in order to add to the overarching system. The key contribution of this work, therefore, is an investigation of two standards in the community and exploring ways to provide interoperability between them. HydroModeler is a software implementation of our work and provides an OpenMI-compliant modeling environment embedded within the CUAHSI HIS HydroDesktop software system. We describe the design and implementation of this prototype software system, and then present an example application in which evapotranspiration is modeled using OpenMI components that consume HIS time series data for input. Finally, we conclude with a summary of our experience exploring the potential for interoperability between data and modeling systems, and suggest ways in which future development can better facilitate connections between the various subsystems needed within an integrated environmental modeling system.

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1. Introduction

Environmental management often requires both observations and models to answer policy questions and to address potential or current problems. It is therefore important to consider approaches for using data management systems in combination with models to study environmental systems. While there are many examples of data management and modeling systems as separate tools (Syvitski et al., 2004; Moore and Tindall, 2005; Kralisch et al., 2005), there are fewer examples of integrated systems capable of handling both of these activities (Argent et al., 2009). Furthermore, the general trend toward standardization in both the data and modeling communities suggests a path forward for combining existing tools that are built from established data transmission and

communication standards. This integration would allow for a broad community of individuals and groups to contribute to an environmental management system.

This paper focuses on two existing technologies, the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS) and the Open Modeling Interface (OpenMI), and explores how they can be combined to create a complete environmental management system. The CUAHSI HIS has been developed with the goal of enhancing access to hydrologic data (Maidment, 2008; Tarboton et al., 2009). Concurrent to this effort, the OpenMI Association has developed a standard to facilitate model coupling and a reference Software Development Kit (SDK) for implementing the standard (Moore and Tindall, 2005; Gregersen et al., 2007). Because the two systems were developed by independent groups, there is no formal mechanism for using both the HIS and the OpenMI together. However, the systems share important similarities that make interoperability possible, as demonstrated in this paper.

[☆] Thematic Issue on the Future of Integrated Modeling Science and Technology.

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The objective of this research is to explore how interoperability between the CUAHSI HIS and the OpenMI can be achieved, and then to use this knowledge to design and prototype a software application that demonstrates system interoperability. The prototype software application, named HydroModeler, is an integrated environmental modeling environment implemented as a plug-in to the CUAHSI HydroDesktop software system (Ames et al., 2009) in order to allow for OpenMI-compliant modeling within the HIS. HydroModeler supports any OpenMI-compliant (Microsoft .NET Framework 4.0) model and enables users to create model configurations where data is supplied by the HIS into simulations and, likewise, data can be written back from a simulation into a local data repository. This data interoperability is possible using two new OpenMI components, a database reader and a database writer. Furthermore, this functionality enables other HydroDesktop tools to work with model output. For example, the HydroDesktop plotting and mapping views provide temporal and spatial visualization capabilities for model outputs.

In the following section we provide further background on the CUAHSI HIS and OpenMI to familiarize the reader with these two technologies. We then present our approach for integrating the HIS and OpenMI, including a summary of the challenges encountered and a discussion of alternative approaches considered. We next present HydroModeler as a prototype application that provides the ability to build and execute OpenMI model configurations that leverage HIS data. An example study is then used to showcase how these systems can be applied to model a hydrologic process. This example study demonstrates a small piece of what could be a much larger environmental or cross-disciplinary model. Finally, we conclude with a summary of the research results and a brief discussion of future research plans.

2. Background

2.1. CUAHSI Hydrologic Information System (HIS)

The HIS can be viewed as three separate but interconnected subsystems: HydroServer, HIS Central, and HydroDesktop (Fig. 1) (Tarboton et al., 2009). HydroServer is a data sharing tool provided as part of the CUAHSI HIS software stack (Horsburgh et al., 2009). It includes a database schema, known as the Observations Data Model (ODM), for storing observational time series (Horsburgh et al., 2008). In a HydroServer, an ODM database is exposed using the WaterOneFlow web service Application Programming Interface (API), and software tools are provided for managing time series data within an ODM database (Tarboton et al., 2009). HIS Central is a metadata catalog that enables search across distributed HIS data. It includes an ontology and controlled vocabulary to mediate semantic heterogeneity across multiple data providers. In basic terms, the ontology provides the structure needed to integrate disparate systems (i.e. data from different sources) and the controlled vocabulary establishes the precise language needed for

inter-system communication (Gruber, 2009). Lastly, the HydroDesktop is a desktop application that enables end users to search, download, and analyze hydrologic data available through HIS Central (Ames et al., 2009). It utilizes a back-end database with a schema similar to the ODM for storing observation data on the user's local machine. The HydroDesktop Graphical User Interface (GUI) is built on an open source Geographic Information System (GIS) platform named MapWindow GIS (Ames et al., 2008) that allows for the extension of core functionality through plug-in software. Plug-in extensions can be developed in the C# (Microsoft .NET Framework 4.0) programming language using a HydroDesktop plug-in interface standard. HydroModeler is one such plug-in extension that adds integrated modeling capabilities to HydroDesktop.

The CUAHSI HIS follows a service oriented architecture (Curbera et al., 2002; Huhns and Singh, 2005) because each of the three systems described in Fig. 1 are interconnected by web services (Tarboton et al., 2009). Hydrologic data is stored in databases throughout the world and are exposed on the Internet using web service standards (Goodall et al., 2008; Tarboton et al., 2009). The HydroDesktop application, for example, obtains metadata from the HIS Central system using web services to identify available datasets. A second set of web services, called WaterOneFlow, are used to obtain these datasets from specific instances of HydroServers, or any other database that is exposed using the HIS web service standards (Horsburgh et al., 2009). This design principle allows the overall HIS architecture to be open and extensible. For example, third party applications that require access to hydrologic data can communicate directly with HIS Central or HydroServer systems, using their respective web services. Moreover, a model can obtain input data directly from a HydroServer, rather than using the graphical HydroDesktop application to prepare input files (e.g. Billah and Goodall, 2011).

2.2. Open Modeling Interface (OpenMI)

The OpenMI is a standard that defines how models exchange data during a simulation run (Moore and Tindall, 2005). It is accompanied by a reference Software Development Kit (SDK) that provides tools for implementing the standard to perform integrated environmental modeling (Gegersen et al., 2007). This research uses OpenMI version 1.4, the current release during the time that the majority of the research was conducted. The OpenMI standard consists of interfaces that can be used to couple models so that they are able to seamlessly exchange data during run time. For example, an integrated model may require coupling watershed, river hydraulics, and groundwater models, as shown in Fig. 2. The OpenMI enables such models to be coupled and exchange data necessary to simulate system interactions and dependencies. This approach enables each model to maintain its own identity so that the model can also run independently as well as within a larger system. Therefore, the OpenMI can be described as a loose integration software architecture (Gegersen et al., 2007) and is in contrast to tight integration approaches where the models are combined into a single system (e.g. Yu et al., 2006; Maxwell et al., 2007; Ahrends et al., 2008). Loose integration implies that models are coupled in a “plug-and-play” manner, such that it is possible to reconfigure how they interact without recompiling the source code (Argent, 2004). While the OpenMI was designed to couple large legacy models for environmental management, it is also possible to create configurations from new components created for research purposes (Bulatewicz et al., 2009; Castronova and Goodall, 2010). One of the most attractive features of component-based modeling is that specific parts of a modeling system can be interchanged to test their individual impact. This

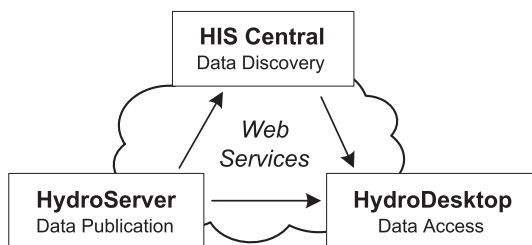


Fig. 1. Overview of the CUAHSI Hydrologic Information System.

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