Soft coupling and protocols through open source programming — the OpenMI standard

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Panta Rhei Everything Flows

Definitions

- **Frameworks**, or **environments**, support **modular** model development through provision of libraries of core environmental modelling modules, as well as reusable tools for data manipulation, analysis and visualisation.
  - » **Workbench** is a suite of tools, standards, documents, and resources that collectively provide a **modular environment**
- Model **interoperation**/Interoperability
- **Engines** (simulators) - Engines, when populated with data, become models
- UML: Unified Modeling Language

Background – model integration and coupling

- model **integration** for at the **operational** level
- **software ecosystem** for flexible, interoperable, and ever-improving research
  - » Process **interactions**
  - » Integrated approach for environmental **management**
- **multidisciplinary** research project
  - » models founded on different concepts, with different spatio-temporal scales, …
- Example
  - » To explore the **cause-and-effect** relationships (in a multi-sector system) e.g. between an emission and its impact on river water quality
  - » environmental **assessment** e.g. the effectiveness of regulatory measures on river quality

Platforms – model integration and coupling

- Different frameworks
  - » Spatial Modelling Environment (SME),
  - » OpenMI
  - » Integrated Component Modelling System (ICMS)
  - » CDMS, etc.

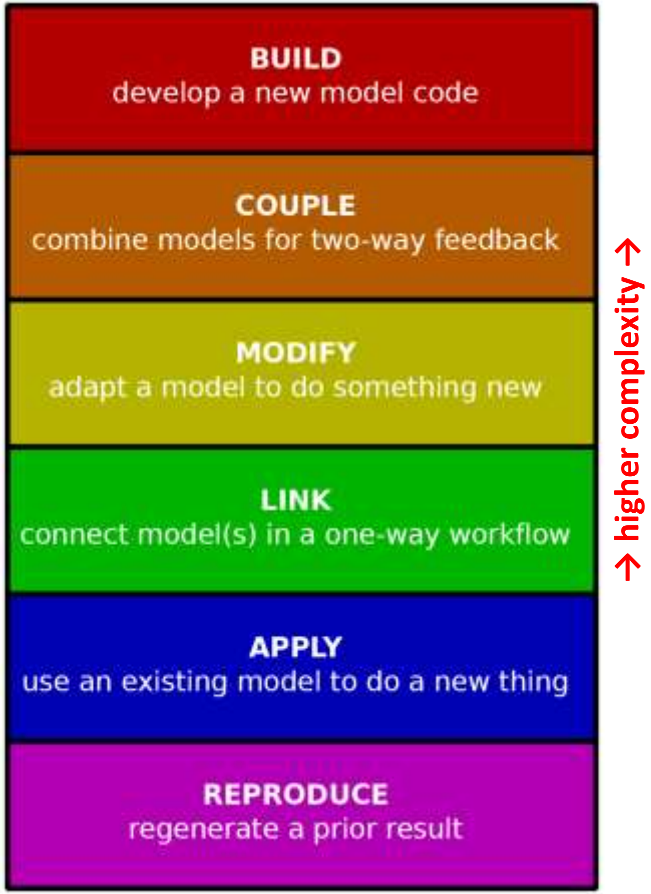

EGU European Geosciences Union

Geoscientific Model Development

CSDMS: a community platform for numerical modeling of Earth surface processes

Gregory E. Tucker[1,2], Eric W. H. Hutton[3], Mark D. Piper[3], Benjamin Campforts[3], Tian Gan[3], Katherine R. Barnhart[1,2,a], Albert J. Kettner[3], Irina Overeem[2,3], Scott D. Peckham[3], Lynn McCready[3], and Jaia Syvitski[3]

CSDMS



Taxonomy of model operation tasks

Platforms – model integration and coupling

- Different frameworks

ELSEVIER

Earth-Science Reviews

Volume 207, August 2020, 103223

Position paper: Open web-distributed integrated geographic modelling and simulation to enable broader participation and applications

Min Chen [a,k,l], Alexey Voinov [b,m], Daniel P. Ames [c], Albert J. Kettner [d], Jonathan L. Goodall [e], Anthony J. Jakeman [f], Michael C. Barton [g,n], Quillon Harpham [h], Susan M. Cuddy [i], Cecelia DeLuca [j], Songshan Yue [a,k,l], Jin Wang [a,k,l], Fengyuan Zhang [a,k,l], Yongning Wen [a,k,l], Guonian Lü [a,k,l]

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Some typical component-based systems (in no particular order).

Name	Features	References
The Community Surface Dynamics Modeling System (CSDMS)	CSDMS is a diverse community of experts promoting the modelling of earth surface processes by developing, supporting, and disseminating integrated software modules that predict the movement of fluids, and the flux (production, erosion, transport, and deposition) of sediment and solutes in landscapes and their sedimentary basins.	Peckham et al. (2013)
Spatial Modelling Environment (SME)	SME is an integrated environment for high performance spatial modelling which transparently links icon-based modelling tools with advanced computing resources to support dynamic spatial modelling of complex systems	Maxwell and Costanza (1997a, 1997b)
Dynamic Information Architecture System (DIAS)	DIAS is a flexible, extensible, object-based framework for developing and maintaining complex multidisciplinary simulations of a wide variety of application contexts.	Simunich et al. (2002), Hummel and Christiansen (2002)
Common Component Architecture (CCA)	CCA supports parallel and distributed computing as well as local high-performance connections between components in a language-independent manner.	Kumfert et al. (2006), Bernholdt et al. (2006)
Earth System Modelling Framework (ESMF)	ESMF is based on the principle that complicated applications are broken into smaller components with standard calling interfaces. A model component that implements the ESMF standard interface can communicate with the ESMF shell and inter-operate with other models.	Hill et al. (2004), Collins et al. (2005), DeLuca et al. (2012)
Object Modelling System (OMS)	OMS allows model construction and model application based on components. OMS v3. + is a highly interoperable and lightweight modelling framework for component-based model and simulation development on multiple platforms.	Skrlisch et al. (2005), Ahuja et al. (2005)
Open Modelling Interface (OpenMI)	The OpenMI compliant components can run simultaneously and share information at each timestep making model integration feasible at the operational level.	Moore and Tindall (2005), Gregersen et al. (2005, 2007), Harpham et al. (2014)
FluidEarth	The FluidEarth platform is based on the concept of writing a 'wrapper' for software codes, and on providing a generic linking mechanism so that any model can be linked to any other.	Harpham et al. (2014)
System for Environmental and Agricultural Modeling; Linking European Science and Society (SEAMLESS)	The SEAMLESS project developed science and a computerized framework for integrated assessment of agricultural systems and the environment.	Janssen et al. (2011), Van Ittersum et al. (2008)
FRAMES	A feed forward modelling framework, employs the component-based approach and incorporates data dictionaries for data exchange. Wrappers are written for each component to read and write data to the dictionaries. The framework then manages transfer of data between components during runtime through an inter-component communication API.	Whelan et al. (2014)
Common Modelling Protocol (CMP)	CMP defines a transport protocol and describes a message based mechanism for packing and unpacking data, executable entry points, and a set of defined messages to transfer variables and events from one model and/or component to others involved in a simulation.	Moore et al. (2007)
BioMA/APES	The focus of BioMA is to run integrated modelling products against spatial databases. It is a direct result from the previous component-based framework called APES, which is aimed to estimate the biophysical behavior of agricultural production systems in response to the interaction of weather, soil and agro-technical management options.	Donatelli et al. (2010)
The Invisible Modelling Environment (TIME)	TIME simplifies the task by providing a high level, metadata driven environment for automating common tasks, such as creating user interfaces for models, or optimizing model parameters. This reduces the learning curve for new developers while the use of commercial programming languages gives advanced users unbridled flexibility.	Stenson et al. (2011)
The Library of Hydro-Ecological Modules (LHEM)	LHEM (http://giee.uvm.edu/LHEM) was designed to create flexible landscape model structures that can be easily modified and extended to suit the requirements of a variety of goals and case studies.	Voinov et al. (2004)
JGrass-NewAge	JGrass-NewAge is a system for hydrological forecasting and modelling of water resources at the basin scale. It has been designed and implemented to emphasize the comparison of modelling solutions and reproduce hydrological modelling results in a straightforward manner.	Formetta et al. (2014)
Science and Policy Integration for Coastal System Assessment (SPICOSA)	The multi-disciplinary project SPICOSA used a common, component-based simulation framework for environmental modelling.	de Kok et al. (2015)
Tarsier	The framework facilitates fast, powerful model development by providing a system for implementing separate model elements as autonomous modules, which may then be tightly and flexibility integrated. It is object-oriented, with integration of modules achieved through the sharing of common objects (and was the precursor of TIME)	Watson and Rahman (2004)
Artificial Intelligence for Ecosystem Services (ARIES)	A web application to assess ecosystem services and illuminate their values to humans in order to make environmental decisions easier and more effective	Villa et al. (2009), Bagstad et al. (2013)

Background – openMI

- OpenMI Association https://publicwiki.deltares.nl/display/OPENMI/Home
- OpenMI is a standard for **coupling** environmental numerical models
- developed by a series of European research projects over a period of over ten years
- Originally integrated *water resource management* → **environmental management**
- Individual models are adapted to become OpenMI components
  - » allowing independent numerical **model <u>components</u> to interact** (exchange data)
  - » without fundamental changes to the core of the components themselves

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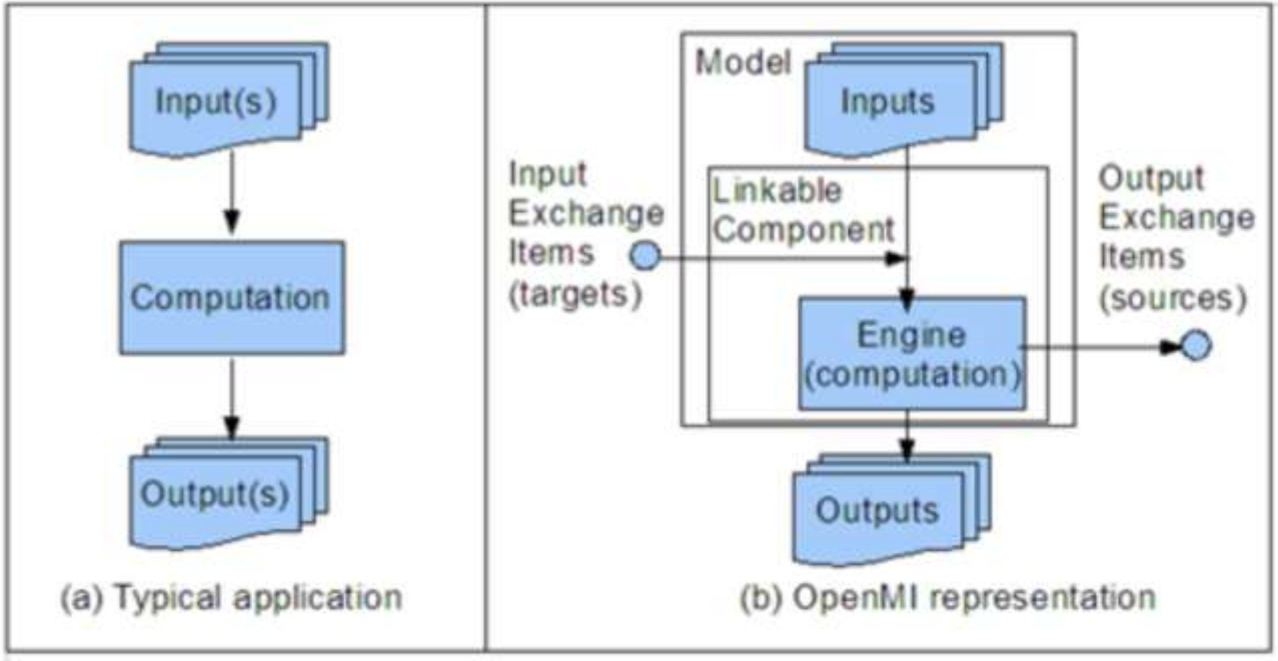
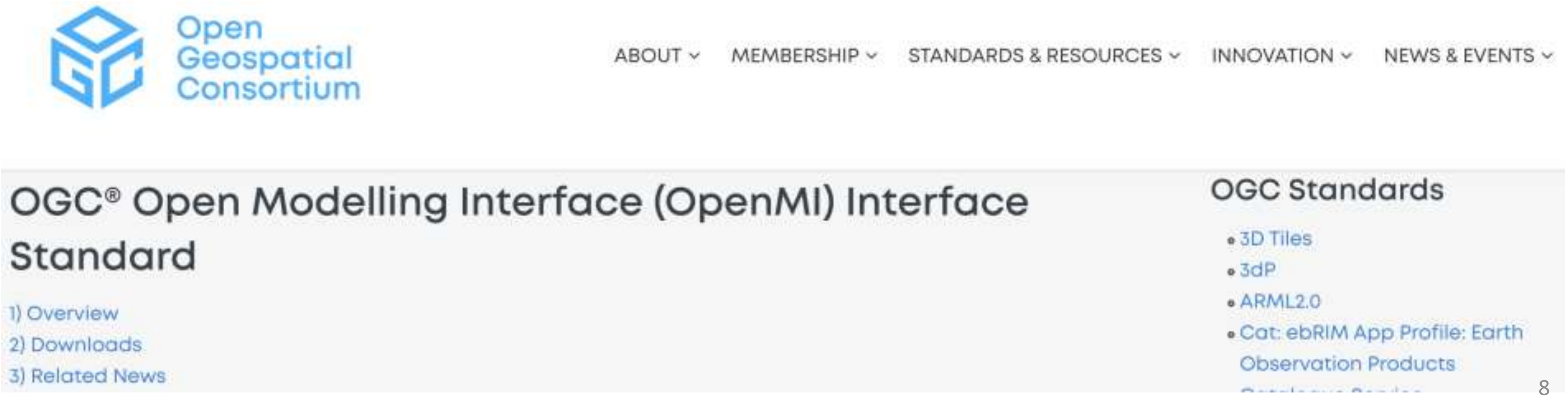


Background – openMI

- It is an open standard and available through the Open Geospatial Consortium (OGC) (http://www.opengeospatial.org/standards/openmi).
  - » OGC: is an international consortium of more than 500 businesses, government agencies, research organizations, and universities driven to make geospatial (location) information and services **FAIR** - Findable, Accessible, Interoperable, and Reusable.



Protocols and Standards

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Environmental Modelling & Software

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Introductory overview: The OpenMI 2.0 standard for integrating numerical models

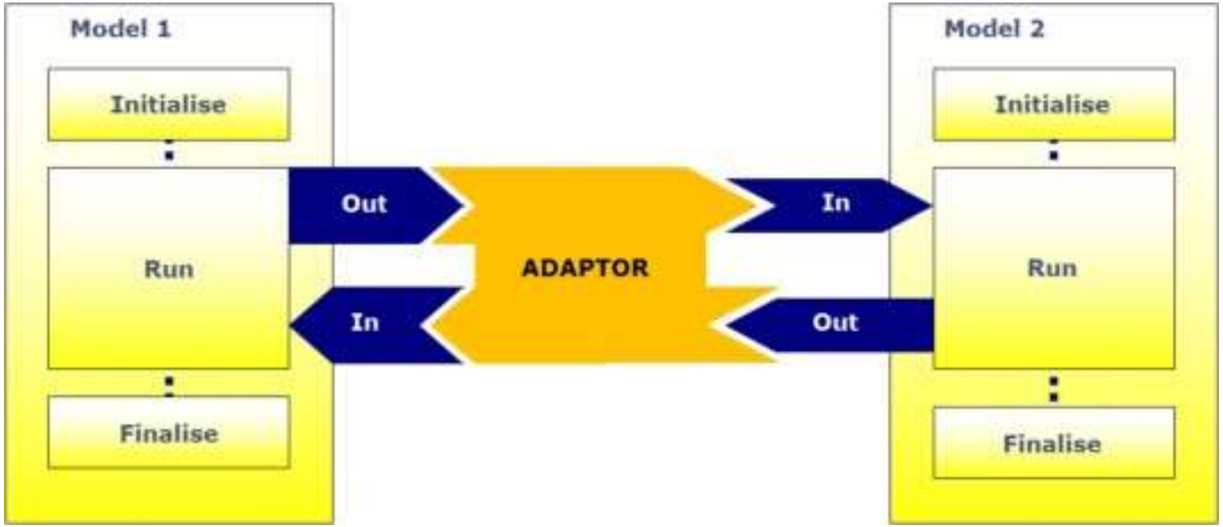
Q.K. Harpham [a], A. Hughes [b], R.V. Moore [b]

Protocols and Standards

- Structure: The OpenMI 2.0 interfaces act as a code wrapper around the core numerical model code.
  - » Migrating models (wrapping pattern)
- Exchange Items
  - » Only Exchange Items will be able to be passed from one numerical model to another via the OpenMI interface.
- Parameters and units
- Spatio-temporal structure
- Adopters

Protocols and Standards

- Adapters
  - » Two independently developed OpenMI 2.0 compatible numerical models can have their inputs and outputs connected according to the desire of the modeller: input exchange items to output exchange items.
  - » Requires adjustment



Protocols and Standards – Example for interoperability

1. Scientific variables are multi-faceted: a phenomenon of observation, physical quantity being measured, spatiotemporal context and reference, mathematical operations applied to transform the physical quantity, etc.

2. terminology varies across disciplines → semantic mediation task two variables represent compatible concepts

   Standard Names (by CSDMS)

   object part (a phenomenon or object of observation)

   quantity part ()

   `land_surface_water__runoff_volume_flux`

   The **double-underscore __** separates the object (surface water on land) from the quantity (the volume flux of runoff). The word “flux” implies a quantity per time per surface area, and thus the implied dimensions are length per time.

Protocols and Standards – Example for interoperability

- Making models OpenMI 2.0 compliant
  - » if it implements a set of interfaces that can connect to and interact with the OpenMI 2.0 component interface IBaseLinkableComponent or its specialisations

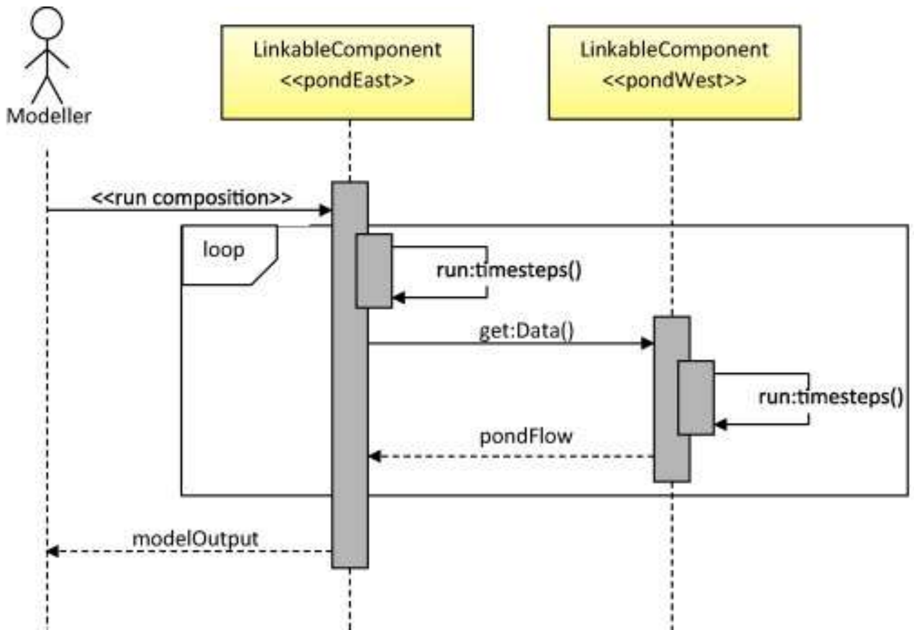
Thus, making a numerical model OpenMI 2.0 compliant can be achieved in two steps:

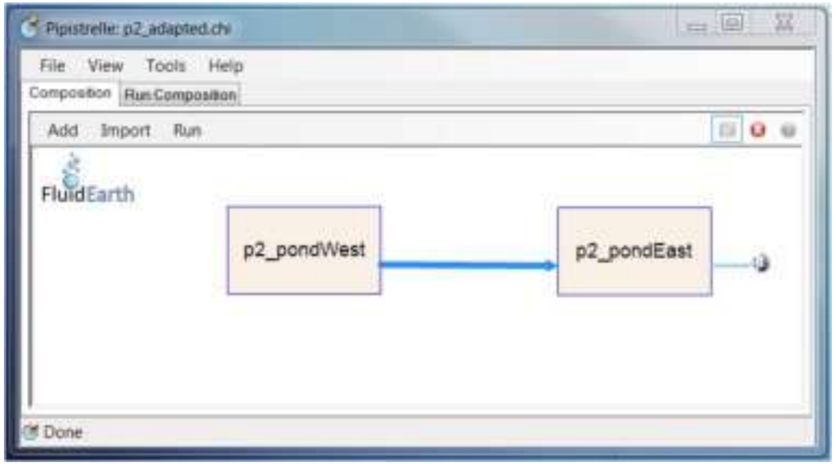
- **Step 1:** Prepare the numerical model code to be consistent with the principles outlined in the above and for mapping to the OpenMI 2.0 interfaces. In particular this applies with respect to Control and Structure, tidy and accessible arrangement of input and outputs to be accessed through Exchange Items, clear definitions of Parameters and Units, clear definition of Spatio-Temporal Structures, and understanding of any potential requirements for use of Adaptors.

- **Step 2:** Connect the relevant attributes of the numerical model into the OpenMI 2.0 interfaces i.e. 'wrap' the model. Software Development Kits (SDKs) are provided with implementations of OpenMI to aid developers in this task (Harper et al., 2016, Harpham et al., 2014).

Implementations of openMI 2.0 – two main components

- **Software Development Kit (SDK)** to facilitate the wrapping of numerical models into OpenMI 2.0 components
- **a Graphical User Interface (GUI)** to assemble compositions of components into compositions and to run these compositions





Resources for future work…

The paper definition of OpenMI can be obtained from its associated OGC (Open Geospatial Consortium) standard definition at https://www.opengeospatial.org/standards/openmi ↗.

Object interface libraries for OpenMI 2.0 standard can be obtained from its associated Source Forge project, https://sourceforge.net/projects/openmi/ ↗. They have been prepared in Java and C#, together with other supporting material.

The OpenMI Association website is available at http://openmi.org ↗.