Geospatial Sensor Web and Self-adaptive Earth Predictive Systems (SEPS)

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Dr. Liping Di
Center for Spatial Information Science and Systems (CSISS)
George Mason University
6301 Ivy Lane, Suite 620
Greenbelt, MD 20770
301-982-0795, ldi@gmu.edu

1. What is Sensor Web

Traditionally, Sensor Web is defined as a web of interconnected heterogeneous sensors that are interoperable, intelligent, dynamic, flexible and scalable. This definition implies that a sensor Web is a hardware network of sensors. Alternatively, the Sensor Web can be defined as a universe of network-accessible sensors, sensory data and information. This definition is more network-centric and includes sensory data and information, but seems excluding the virtual sensor, which is defined in next paragraph.

In this position paper, I propose a sensor web definition from computational viewpoint and under the service-oriental architecture (SOA) and web service environment. *A sensor web is a group of interoperable web services which all comply with a specific set of sensor behaviors and interfaces specifications.* In this definition, a web service which contains an algorithm or simulation model could be a senor in a sensor web as long as its interfaces and behaviors comply with the specifications. We call such a sensor the virtual sensor. From computational viewpoint, there is no different between a real sensor and a virtual sensor. By using this definition, we can classify a sensor web based on the specifications it complies. For example, a sensor web that complies with OGC Sensor Web Enablement (SWE) specifications can be called an OGC sensor web, while a sensor web that complies with IEEE sensor web specification can be called an IEEE sensor web. A sensor web can be applied to a specific application domain. By combining the application domain and the specifications it complies with, a sensor web can be uniquely identified.

By defining a sensor web as a group of interoperable web services, all features of the web services are also applicable to the web-ready sensors, which include but not limit to the dynamics, flexibility, plug-in-and-play, self description, and scalability. This also implies the data and information generated by individual web-ready sensors are interoperability and the sensor services are chainable.

2. Geospatial Sensor Web as the Future of Earth Observation

Geospatial sensor web is the sensor web that performs Earth observations (EO). Because of the advantages of sensor web comparing with the traditional standalone sensors as discussed in Section 1, we envision that in the future the major new EO sensors will be web-ready. Some existing sensors will also be converted into web-ready sensors, such as EO-1. The legacy data systems and even simulation models, which provide data and information to applications, can also be simulated as a virtual web-ready sensor. Therefore, by using my sensor web definitions stated in Section 1, all EO data and information sources can be unified under the Web service architecture and all sensors can be accessed through standard service interfaces. Therefore, sensor web will greatly enhance the usability, interoperability, flexibility, and sharing of Earth observation (EO) resources. The following sections will discuss a general framework and architecture for coupling sensor web with Earth system models in SOA.

3. The Self-adaptive Earth Predictive System (SEPS) Concept

The self-adaptation concept is the central piece of the control theory widely used in engineering control systems. Such a system contains a predictor, which takes initial conditions and makes an initial prediction, and a measurer, which measures the state of a phenomenon. Through a built-in feedback mechanism, the predictor compares measurements with the predictions and makes adjustments of its internal state. With the prediction-feedback mechanism, a system soon learns the pattern of the real-world phenomenon and makes accurate predictions.

The self-adaptation concept can be applied to Earth system prediction. The resulted system is called Self-adaptive Earth Predictive Systems (**SEPS**). A SEPS consists of an EO component and an ESM component, coupled by a SEPS framework component. EO measures the ES state while ESM predicts the evolution of the state. A feedback mechanism processes EO measurements and feeds them into ESM during model runs, as well as initial conditions. A feed-forward mechanism compares ESM predictions with scientific goals for scheduling or selecting further optimized/targeted observations. The SEPS framework automates the feedback and feed-forward mechanisms (called the **FF loop**). Mature geospatial standards can be used to build the SEPS framework that can work with various ESMs and EO sensors/data systems. The major part of the EO component will be geospatial sensor webs.

4. Architecture of the SEPS Framework

The SEPS framework uses service-oriented architecture (SOA). Every function in the framework is a service performing a well-defined set of actions. Individual services can be chained together to solve complex tasks (Di, 2004). The SEPS framework defines and implements service subcomponents of the framework and interface protocols between them for automating the FF loop. Figure 1 shows the overall architecture. OGC defines sensor web as a web of heterogeneous interoperable, intelligent, dynamic, flexible and scalable geospatial sensors interconnected through standard interfaces and accessible through the Web. The scope of OGC sensor web is also shown in the figure. SEPS is much broader than the OGC sensor web. The standard interfaces in the framework allow dynamic plug-and-play of ESMs and EO sensors. The framework consists of five subcomponents interconnected by standard interfaces, including Data Discovery and Retrieval Services (DDRS), Data Pre-processing, Integration, and Assimilation Services (PIAS), Science Goal Monitoring Services (SGMS), Data and Sensor Planning Services (DSPS), and Coordination and Event Notification Services (CENS).

5. Standard Interface Protocols

The framework adopts the standard interface protocols discussed in the following sections to glue together different components.

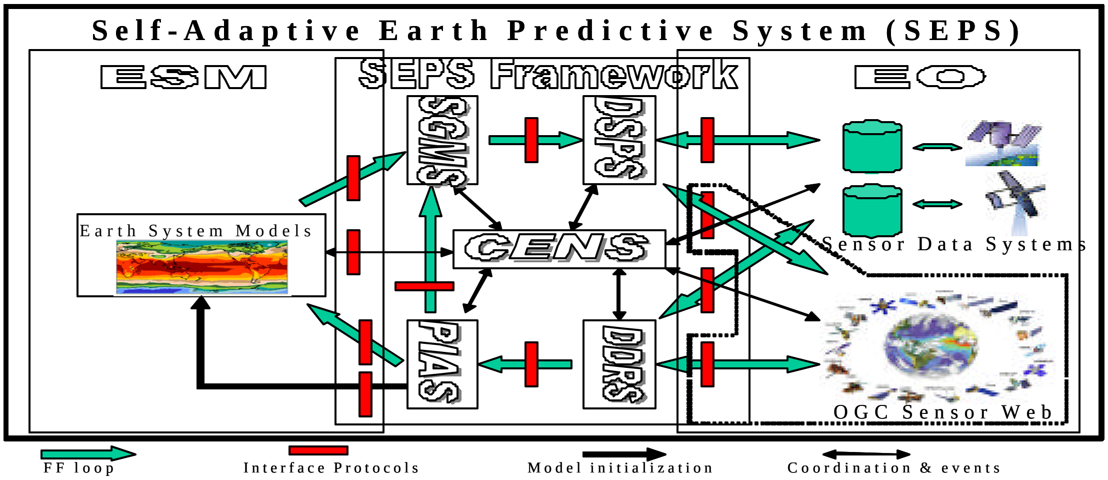

Figure 1. SEPS and the SEPS Framework

5.1. OGC and ISO Sensor Web Standards

In the past several years, OGC and ISO have been developing standards and protocols for the geospatial sensor web, including ISO 19130 – Sensor Data Model for Imagery and Gridded Data (ISO, 2004) and the OGC Sensor Web Enablement (SWE). The ISO 19130 provides the conceptual framework for enabling the sensor web. The OGC Sensor Web Enablement (SWE) initiatives have developed six implementation specifications based on the assumption that all sensors are connected to the Web: SensorML (Botts, 2005), Observation and Measurements (O&M) (Cox, 2003), Sensor Planning Service (SPS) (Simonis, 2005), Web Notification Service (WNS) (Simonis & Wytzisk, 2003), Sensor Alert Service (SAS), and Sensor Observation Service (SOS) (Na and Priest, 2006). When they work together, it is possible to use Web services to discover, access, and control sensors.

5.2. Geospatial Interoperability Protocols

The framework works with both web-ready sensors through SWE protocols and legacy sensors accessible only via their ground data systems through the following protocols.

5.2.1. OGC Data Interoperability Protocols

The most popular OGC protocols for data access include Web Map Services (WMS) (de la Beaujardiere, 2004), Web Feature Services (WFS) (Vretanos, 2004), Web Coverage Services (WCS) (Evans, 2003), and Catalog Services - Web Profile (CSW) (Nebert and Whiteside, 2004). WMS, WFS, and WCS are designed for interoperable access to geospatial data in the form of a map (e.g., JPEG picture), feature type (e.g., weather station data), and grid data (e.g., spaceborne images), respectively. CSW is designed to provide catalog services for both data and services (Nebert and Whiteside 2004). Because most NASA Earth science data from sensors and models are in the grid form, the most relevant OGC protocols are WCS for data access and CSW for data discovery (Di, 2006).

5.2.2. The OPeNDAP protocol

The Open-source Project for a Network Data Access Protocol (OPeNDAP), developed by OPeNDAP Inc., defines the interface between OPeNDAP clients and servers for transmitting science data (Cornillon et al., 2003). The protocol provides data types to accommodate gridded, relational, and time-series data. It also allows users to define their own data types (Gallagher et al., 2005). OPeNDAP has been used extensively in the oceanography, meteorology, and climate communities.

5.3. Earth System Modeling Framework (ESMF)

ESMF defines an architecture framework for composing multi-component applications and includes data structures and utilities for developing model components. ESMF defines standard function methods for organizing a model component. It also defines an ESMF data structure (ESMF state) for communication between components. An ESMF component has to pack model import and export data into an ESMF data structure and conform to a standard calendar (ESMF, 2005).

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