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An innovative system for sharing, integration and visualization of heterogeneous 4D-information

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ABSTRACT

Treating the time dimension (i.e., the 4th dimension) of geospatial parameters, likewise the other dimensions is important for some applications to better understand the possible space-time relations among the physical parameters underlying the dynamics of complex phenomena. In this paper we present the potential of an innovative solution, named 4 Dimensions Environmental ObServation (4DEOS), which is a platform able to handle the 4th dimension in an asynchronous way (i.e., to visualize more signals, holding some of them fixed in the time domain while moving others over time). 4DEOS is based on a Client-Broker-Server architecture for the easy integration and visualization of heterogeneous, asynchronous, geospatial products. The prototype system was evaluated in the case of earthquake prediction studies where the asynchronous visualization of independent observations could allow a timely identification of the spatial correlations appearing at different time lags, which could be missed using other existing 4D Geographic Information System software.

Software availability

Software name: 4DEOS (4 Dimensions Environmental ObServation)
Developers: Rossana Paciello, Irina Coviello and Paolo Bitonto
Year first official release: 2012
Hardware requirements: standard PC
System requirements: Microsoft Windows (XP or later), Java (version 1.6 or higher)
Program language: Java
Program size: 420 MB
Availability: "Downloads" area in http://www.pre-earthquakes.org (user registration is required)
License: Free under a GNU General Public License (www.gnu.org) agreement
Documentation for users: Manual

1. Introduction

The analysis of complex natural phenomena often requires the integration of heterogeneous time-dependent datasets in order to investigate the possible correlations among the underlying physical and chemical parameters. Depending on the spatial and temporal dynamics of each parameter, such datasets could have a different spatial resolution and could be asynchronous (i.e., not recorded together, at same time) and/or asynchronously visualized for specific applications.

Ascertaining the occurrence of spatiotemporal correlations among the recorded signals, also at different time lags, is crucial for many applications. For instance, in the case of flood forecasting, an anomalous variation of the soil moisture measured by meteorological satellites (e.g., Lacava et al., 2010) could be compared with the precipitation forecasts for the following days to dynamically update the flood risk estimates. Also in the case of earthquake events (e.g., Bonfanti et al., 2012) and volcanic eruptions (e.g., Marchese et al., 2014), anomalous signals coming from a multiparametric observation system and appearing at different times,

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could be better compared each other using tools able to dynamically and asynchronously visualize multi-parametric geospatial datasets. This suggests that the temporal dimension should have the same importance as the other ones.

The explicit representation and analysis of spatiotemporal data were first theorized by Langran and Chrisman (1988). Since the beginning of the 1990s, several efforts have been made to build geographic databases and platforms (Abraham and Roddick, 1999; Langran, 1993; Peuquet and Duan, 1995; Rasinmaki, 2003; Galton, 2004; Pelekis et al., 2004; Zhou et al., 2004; Le, 2005; Peuquet, 2005; Zhu et al., 2008; Fan et al., 2010) specifically devoted to space-time data management and analysis. Different approaches were proposed and various data models and platforms were developed, also supported by technological advancements (Maceachren et al., 1999; Tryfona and Jensen, 1999; Shi and Zhang, 2000; Wang et al., 2005; Lee et al., 2006; Shaw et al., 2008; Shaw and Yu, 2009; Vivar and Ferreira, 2009; Pultar et al., 2010; Sadahiro, 2002; Sugam et al., 2013; Gebbert and Pebesma, 2014).

At present spatiotemporal correlation analysis and time-varying signal visualization are typically performed using geospatial data management systems like Geographic Information System (GIS) and their derivatives that allow users to overlay spatial data and to manage time as an attribute of the spatial reference (Pelekis et al., 2004). This kind of architecture, however, does not incorporate the temporal indexing into the GIS itself (Peuquet and Duan, 1995; Peuquet, 2001; Galton, 2004) and the representation of asynchronous datasets over time does not take into account the full dimensions of a dataset and its continuous or discrete variations. Consequently, customized systems have to be designed and developed in each different application to properly manage data in the space-time domain (Le, 2012). Present geospatial data management systems permit users to visualize spatial, time-dependent signals thanks to specific functions, but the time variations of such signals are visualized overlapping one another, with the consequence that it is impossible to move a specific signal over time and visualize its time variations while keeping the others fixed. The 4 Dimensions Environmental ObServation platform (4DEOS), a Client-Broker-Server (CBS)[1] platform, here presented is able to visualize together several asynchronous spatiotemporal data/products provided by servers and queryable by authorized users. The innovative aspect of 4DEOS is quite evident, giving the platform the possibility of visualizing spatial, time-dependent signals in a simultaneous or asynchronous mode so that the study of their temporal evolution may be more easily carried out. Users can move one or more signals while holding others fixed in the time domain.

In the following paragraphs we describe the detailed 4DEOS architecture and its utilization to study a particular application: the detection of earthquake precursor signals, developed in the framework of the EU-FP7 Project PRE-EARTHQUAKES (Processing Russian and European EARTH Observations for earthQUAKE precursors Studies, http://www.pre-earthquakes.org).

2. The 4DEOS architecture

The 4DEOS platform was designed and developed with the aim of offering clients a single entry-point to visualize heterogeneous data (e.g., maps, vertical profiles, punctual time series related to different observation times and/or geographic areas) shared by different data providers. 4DEOS does not use a standard client/server architecture, where a client, needing a service from a particular server, sends a request to an appropriate server and the server performs the requested service, returning results to the client. This client/server architecture works fine only for small systems (i.e., when clients interact with a small set of servers - Adler, 1995), while, in growing and evolving systems like 4DEOS, individual clients need to be constantly updated to take into account the addition of new servers and services (Adebayo et al., 1997).

4DEOS is based on a service-oriented CBS architecture introducing a middle component between clients and servers, called broker, which receives requests from clients, identifies appropriate remote servers, forwards requests to servers and transmits results to clients. It maintains centralized information (e.g., data available in each remote server, authorized clients as well as data that can be requested by each of them) so that clients need to know nothing about the existing servers, just how to interact with the broker (Fig. 1). Each 4DEOS server node has the task of producing and (if necessary) converting with specific converter tools data/products from a particular data provider format to a standard one (e.g., shape file format). This task is typically performed by the broker component, whereas in the 4DEOS architecture this role is assigned to the servers, because the data sharing process is made in a context where data owners (server nodes) are generally reluctant to an actual transfer of files, especially when their data have an added value or are very expensive to acquire and maintain. In the 4DEOS architecture owners expose their data/products via web services, following Open Geospatial Consortium (OGC) standards (http://www.opengeospatial.org; Open Geospatial Consortium, 2005, 2006, 2008), which can be queried only by the broker component. In particular, each server node is configured with a set of open source software:

- Converter tool, different and specific for each single node. It is written in Java and performs the conversion of data/products from the provider characteristic format to a standardized vector format (i.e., shape file);
- Ingestor tool, based on GeoBatch Java software (http://geobatch.geo-solutions.it). It stores shape files in a PostgreSQL database with POSTGIS extension (http://postgis.refractions.net/) and publishes data/products as OGC WMS (Web Map Service) services in GeoServer (http://geoserver.org/).

Besides passing the requests from clients to servers, the broker component manages the security policy that, in order to support and encourage data sharing, was deliberately based on the concept that "the more data you share, the more data you obtain". This principle, here abbreviated MOMO (More Offer More Obtain), was introduced to provide data access according to each provider's contribution; for example, if a data provider shares data relating to a specific geographic area, he will be able to view only the data shared by other providers that refer to the same geographic area. This concept is implemented in the broker by using 52° North Web Security Service (WSS, http://52north.org/) to define multiple levels of data access authorizations. Thanks to XML configuration files, the broker retains information about i) the data/products shared by each server node; ii) the clients enabled to access the 4DEOS platform and iii) the data/product use restrictions concerning each client (for instance geographic areas).

It is possible to add a new server node to the 4DEOS system at any time provided that the system administrator deems the data/products useful for a specific application. In this case, the broker administrator adds to the list of available data the WMS services provided by the new server node and, each 4DEOS Client can visualize the new data/products at the next access (if enabled). In

[1] The Client-Broker-Server pattern architecture allows clients to access remote servers through the broker, a "middle" component, whose responsibility is the transmission of requests from clients to servers, as well as the transmission of responses back to the client.