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Chapter XV
Towards a Virtual Enterprise Architecture for the Environmental Sector

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ABSTRACT

This chapter introduces a virtual enterprise architecture for environmental information management, integration and dissemination. On a daily basis, our knowledge related to ecological phenomena, the degradation of the natural environment and the sustainability of human activity impact, is growing as a consequence raises the need for effective environmental knowledge exchange and reuse. In this work, a solution among collaborating peers forming a virtual enterprise is investigated. Following an analysis of the main stakeholders, a service-oriented architecture is proposed. Technical implementation options, using Web services or software agents, are considered and issues related to environmental information management, ownership and standardization are discussed.

INTRODUCTION

On Service-Orientation

Service oriented approaches attract the broad interest of the scientific community, investing on the added value for the digital world of tomorrow. The promising point of service orientation is the synergy of computer science with artificial intelligence theories and computer networks practices. The primitives of distributed computing, the semantic Web, human-computer interaction, software engineering and agent computing are put together in order to design and deploy open, complex yet intelligent and adaptive computer systems that are based on simple agents of fine granularity, which, in turn, provide services in virtual enterprise (VE) environments.

Virtual enterprise architectures could be valuable for efficient information processing and open, loosely coupled service integration, not only in business-related sectors, from where they originate, but also in non-for-profit sectors. For example, consider these sectors related with public domain data and citizen-centered services in the context of e-government, e-health, e-agriculture, e-environment, e-science and so forth. In such a setting, the notion of a virtual enterprise is rather decoupled from its narrow business context, and extended to a broader scheme that accommodates constellations of cooperating service-providers. Service orientation became quite fashionable lately in several implementation variations, as those of software agents, Web services or grid computing. Each one of the technical solutions has advantages and disadvantages that make it more suited in some types of applications. For example, software agents are considered to be active entities, able to take initiatives, in contrast with Web services, which are required to be invoked, that is, operate in a passive way. In this respect, agents are well suited in competitive environments, that is, as those of knowledge brokering and auction-like environments, while Web services are typically used for integrating heterogeneous components in open environments. Finally, grid computing seems more appropriate for computationally-intense applications. Whatever the application case or the suitable technical approach might be, unarguably, service orientation and virtualization remain a critical characteristic that aims in overcoming system elements capabilities through the composition of fine-granularity service elements with the ultimate goal of providing added-value services in dynamic environments.

This chapter explores the potential of formulating virtual enterprises for the environmental sector. In particular, Section 2 sets the background by introducing concepts related to environmental management information systems (EMIS) and the major challenges for environmental information processing and dissemination. In Section 3, a virtual enterprise architecture for environmental information management is introduced and Section 4 specifies the operational fashion of such a virtual enterprise. Section 5 summarizes latest developments on the field, and discusses the potential for wide-range adoption of virtual enterprises in the environmental sector.

ENVIRONMENTAL INFORMATION AND CHALLENGES

Environmental Data

Environmental data, although considered as public domain, have not been treated as such so far. Environmental information, either collected by public institutes, private industries or generated as a result of scientific computations in academia, has been kept for long in nonreusable, legacy systems and reports. Therefore the vision for enabling access to information and the provision of value-added services that will benefit from the information society initiatives, technologies and tools, often referred as e-environment, or e-agriculture applications, is still in infancy. Nowadays, there are ongoing efforts on defining standards for sharing data about the natural environment, including these published by the US Environmental Data Standards Council in January 2006 (EDSC, 2006) along with the standards developed gradually since 1994 by the european environment information and observation network (EIONET, 1994) and the guidelines (on vegetation plots and classifications) of the Ecological Society of America (VEGBANK, 2006). Also, Food and Agriculture Organization (FAO) of the United Nations has recently made its thesaurus of food and agricultural terms, publicly available through the AGROVOC Web services (AGROVOC, 2006). This task is part of FAO's activities for establishing agricultural information management standards. Significant is the contribution of the OpenGIS specifications by the Open Geospatial

Consortium (OGC, 1994) for the standardization of geo-referenced data, which are very common in environmental applications.

However, it is still a long way to go for disseminating effective environmental information, as there still are problems of data availability and quality that need to be addressed. As Dave Swayne underlined:

the problems of data quality and availability in environmental systems are areas of research that continue to require support" and that "the advances in database technology are not uniformly available in the environmental domain (Swayne, 2003).

Common practice has proven that environmental data are usually stored in nonreusable raw formats, situated in sparse locations and managed by different authorities, which ultimately raise obstacles in making environmental information accessible. With the growing concern of the public for the sustainability of the planet and the degradation of the natural environment, environmental information, data acquisition management and processing and dissemination, becomes a key element for the sound justification of environmental studies, integrated assessment and policy making. A second issue related to environmental studies has to do with the scaling complexity and reuse of prior studies and models in new application areas. Open services for both data and model access and reuse are one of the important components that can boost future developments in the field. This chapter argues that service orientation and the formulation of virtual enterprises can be utilized for overcoming both of these two obstacles.

Environmental Management Information Systems

Environmental management information systems (EMIS) is a broad term that we use as an umbrella for a range of IT systems related to natural resources data management, varying from environmental databases, simulation packages, reporting tools or visualization applications, geographical information systems (GIS), to extremely complex systems such as environmental decision support systems, or integrated assessment toolkits. An environmental management information system can be considered as an enterprise information system that provides efficient and accurate access to knowledge elements related to information about the natural environment. Collections of data sources and databases, simulation algorithms and environmental models, or decision support modules can be parts of an environmental management information system, which packages them together for addressing complex problems.

Among the challenges that modern environmental management information systems have to face is the documentation and dissemination of their results, ultimately via the provision of information services. Significant efforts are required for providing environmental information services to broad audiences, through the exploitation of digital technologies. Modern environmental management information systems are required to broaden their system goals and core requirements for encapsulating open dissemination e-services. Traditionally, environmental management information systems are developed for specific case studies, therefore the generalization of the approach and the potential reuse of the tools is a very seldom situation. This is partially an intrinsic characteristic of environmental systems, as model configuration and adaptation to local conditions is required. However, the disadvantages of EMIS development that do not confront to (any) common specifications become evident to the environmental community. Knowledge sharing, in any forms from raw data to sophisticated environmental model implementations, has become an increasingly important aspect of sound environmental management. As a consequence, the need for modular, service-oriented approaches rises to prominence.

This chapter investigates the potential of creating virtual enterprises for managing and disseminating environmental information, and summarizes recent developments towards this direction. Given the diversity of standards, formats and practices in collecting, managing and storing environmental data, alongside with the emerging need for sharing and disseminating environmental information to wide-ranging audiences, modular service-centered approaches, which form loosely-coupled synergies in open environments, can be the medium for overcoming the existing problems and meeting the requirements.

VIRTUAL ENTERPRISES FOR ENVIRONMENTAL INFORMATION

The Main Users

Day by day natural resources, the physical environment, and sustainability attain the interest of our society. As a result, the community of stakeholders asking for environmental information, from raw measurements to model simulation results or other kind of studies, is growing rapidly. In this respect, there is an emergent need for sharing environmental information, among diverse and cross-disciplinary audiences. This is one of the major challenges that environmental management information systems are facing today: disseminating environmental information across a broad spectrum of potential end–users.

The major stakeholders involved in the lifecycle of environmental information are illustrated in Figure 1. They consist of the scientific community, governmental bodies and institutions, industry and the business sector, nongovernmental organizations and the wide public. Obviously, each one of them has its own perceptions, goals, objectives and interests on the environment and natural resources, which signifies the conflicting perspectives on environmental data interpretations. The main stakeholders and their involvement in the lifecycle of environmental information are summarized as follows:

a. **Environmental institutes:** Mainly occupied with the collection and the analysis of environmental data
b. **Scientific community:** Responsible for the study of the natural phenomena involved; note that both environmental institutes and the scientific community are proposing policy options (alternatives) to the governmental bodies.
c. **Industry and the business sector:** Required to monitor the environmental effects of their activities, as a result of legal obligations, or even of their marketing strategies (as for example the ISO19000 family standards (ISO TC 211, 2004), the Eco-label products (ECO-LABEL, 1994), EMAS certifications (EMAS, 1995-2001), green technology campaigns, etc)
d. **Government and governmental bodies:** Have the main responsibility of decision making and enforcing regulatory policies.
e. **Nongovernmental organizations:** Exist for a variety of purposes related to the preservation of the natural environment, and have very strong interests in accessing environmental information; NGO's participate in consultation procedures for policy-making and influence policy-makers to adopt environmental-friendly options.
f. **Public:** Generally interested in the preservation of the physical environment, natural resources and biodiversity, as a significant factor of every-day quality of life

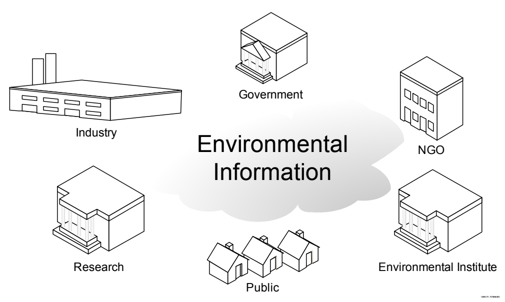
From the description above, it becomes quite evident that there are significant disagreements among stakeholders' interests, which result to clashing interpretations of environmental data, as the basis for justifying policies, business-activity orientation and the expenditure of natural resources. Even if the various interpretations of environmental data are subjective, conflicting or overlapping, and raw environmental measurements often suffer from low reliability, there is a common, emergent need for *sharing environmental data*. In Figure 1, we illustrate the main stakeholders involved in environmental information management, as players around a cloud of environmental information, which they want to contribute in its creation, have effective access to it, and ultimately share.

On Virtualization of Environmental Information

In a collaborative setting that involves all the abovementioned users, environmental data need to be shared and re-used in different contexts and for divergent purposes. The virtualization of a collaborative environment is essential for treating environmental information as a common asset that is shared among peers, instead as a resource in scarcity that peers strive for. Environmental information is required to become a *virtual resource* that is manipulated by all virtual organization peers. In such a setting, the members of a virtual enterprise are enabled to construct scientific workflows for combining original data sources, with environmental models, reporting tools and consequently achieve their own goals.

The virtualization of environmental information, though, raises two very important issues: one is data standardization, and the second is related to data ownership and rights of disclosure. Related to the first one, XML documents associated with ontologies defining scientific data observations and measurements could be the way for resolving issues related to standardization. The success stories from several business sectors (i.e., in e-publishing, or in business-to-business services) are showing the way for similar development in environmental data management. Consider for example the contribution of ISBN/ISSN numbering system in the development of publishing business in a global scale, or the ebXML business standards. (See related the Organization for the Advancement of Structured Information Standards (OASIS) specifications available at: www.ebxml.org). Similar approaches for standardization of environmental data are required to be established, as those initiatives discussed earlier. A second aspect relates to issues of ownership and disclosure. On this front, the digital rights management frame could be followed. Although free access to environmental data is still mandated by the public's right to know about human health and environmental issues, there are often conflicts with other interests. For example, industrial patent protection, intellectual property rights

Figure 1. Main stakeholders to environmental information



or private information and privacy issues often conflict with the amount of information available. Also, note that even if in many countries there is a legal obligation for environmental reporting and dissemination, the frequency and scale of reporting is an issue of dispute among peers. Such issues of scale and access rights need to be handled effectively within a virtual enterprise for environmental data processing.

A FUNCTIONAL VIRTUAL ENTERPRISE FRAMEWORK ARCHITECTURE

Abstract Agent Roles in a Virtual Enterprise

To realize the requirements for making environmental data as commonly available as virtual resources, an abstract virtual enterprise architecture is presented which accommodates common stakeholders' needs and the requirements of sharing public domain data. Within the virtual enterprise, stakeholders can be represented, as agents that could potentially realize three roles (also discussed in Athanasiadis, 2006).

a. **Contribution agents:** These agents act as data fountains of the system and implement the appropriate interfaces to grant access to raw collections of environmental information. Contribution agents could be located in geographically remote locations. Contribution agents provide data gathering, and preprocessing services, including activities like filtering, standardization and normalization.
b. **Data management agents:** These agents are responsible for data fusion and processing. Data management agents operate as knowledge brokers, and are occupied with orchestration, and synthesis and querying activities and the calculation of environmental indicators.
c. **Distribution agents (DA):** These agents are the marketplace of environmental information, as they are occupied with publishing data to the final audiences. Distribution agents deliver the final data implement custom interfaces to the end-user applications.

These three roles are considered as agents to underline their proactive behavior within a virtual organization. To shed some light on this argument, contribution agents are not considered simply as a Web service or portal-like function that can retrieve environmental information upon request, that is, in a passive way, rather they has the responsibility to make available online resources. In this way, contribution agents take the initiative and make environmental information available to the virtual enterprise. In a similar fashion, data management agents capture information becoming available and exploit it appropriately. This could mean that, for example, that they run simulation models or execute environmental assessment toolkits as soon as the required inputs become available. Consequently, distribution agents are constantly updating end-user applications as environmental data and indicators are offered. In such a situation, a virtual enterprise for environmental information management and processing operates as a vigorous virtual organization that intentionally delivers tasks, instead of responding to final-audience requests. Agency of the three roles has the meaning of purposive action and proactiveness, as opposed to passive invocation of available services, rather than implying a technical restriction on the implementation side.

Integration and Demonstration

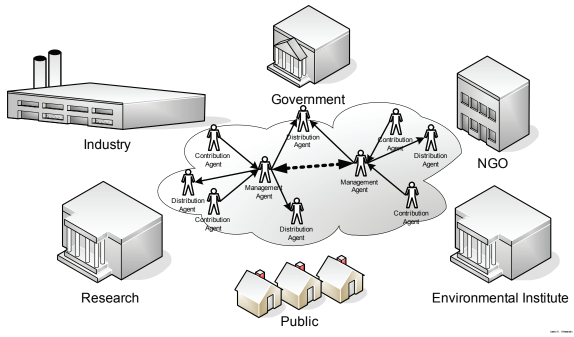
The integration of the previously discussed agent roles in a generic service-oriented architecture is presented in Figure 2. The main stakeholders involved in environmental data processing can engage services of three agent roles, based on their needs, interests or priorities. However, it must be pointed out that such an architecture requires that all agents in the virtual enterprise should adhere common semantics and standards in environmental data representation, as for example the ISO19100 family of spatial information standards. Ontologies could play a vital role in the definition of a general cognition within the virtual enterprise, that is, for specifying shared terms, vocabularies and data constructs. They could also be used for the integration/mediation of data with dissimilar semantics.

In Figure 2, an example virtual enterprise architecture is presented: we assume that industry, research, NGO and environmental institutes employ (several) contribution agents for "registering" their data and making them available within the virtual enterprise. Similarly, government, NGO, research and the public employ their distribution agents for granting access to the environmental information services available. Knowledge brokering and mediation is performed through the management agents which fuse data coming from contribution agents, process and combine services and ultimately make them available to distribution agents. Note that in this example the roles employed by each stakeholder are indicative. A detailed design of such a virtual enterprise may vary, depending on the technical solutions selected for deployment. Nevertheless it should include functionalities that support an open architecture, where agents of generic types may register and operate. In this respect, the requirements for extensibility and reusability are achieved, along with main objective for service composition and orchestration. Also, it should be pointed that each stakeholder could employ more than one agent, of the same or dissimilar types, according to their needs. Agent communication and service composition is an intrinsic characteristic of the proposed system.

Implementation Considerations

The implementation of the system could rely either on Web services or software agent implementations, acting as service providers in an open, virtual, collaborative environment, which undertakes environmental information management tasks. In this way, a virtual enterprise is formulated that can both tackle the obstacles of legacy systems, data noise and redundancy, lack of data standardization and variety of data formatting and aggregation, and to (semi) automate

Figure 2. An example virtual enterprise for environmental information management



the environmental data review processes by incorporating decision support capabilities (i.e., see Athanasiadis & Mitkas, 2004). Virtual enterprises for managing environmental data can ultimately come out with solutions for providing advanced information services to a wider user group. The need for conducting scientific workflows and the integration of environmental models, integrated assessment tools or raw environmental datasets can be also achieved within a virtual enterprise. In this way, future environmental studies could be built using existing components that are available as services from the peers of the virtual enterprise. Data sources, simulation or optimization models, and dissemination platforms are made available within the enterprise and can be reused for building up new services.

Overcoming the Obstacles of Standardization and Ownership

Some could consider that the development of virtual enterprises in the environmental sector is unrealistic, given the poor solutions available related to problems of environmental information standardization and ownership. However, a more positive reading of the situation reveals that even by investigating the virtualization of environmental information had brought forth these problems, essential to environmental data management, modeling and software development. Therefore, the virtualization of environmental information should be considered as a motivation to tackle such problems, and as a part of their remedy. The adoption of service-orientation in environmental software, along with the virtualization of environmental information will eventually lead to solutions of these data-related problems. In the presented architecture, we consider environmental information to be provided in the virtual enterprise through the contribution agents. Let a contribution agent *a* be responsible for providing access to some data source. Through its proactive behavior, Agent *a* can require from the potential "consumers" that request portions of the date, to show credentials of their rights for accessing the data. Agent *a* may contact other services of the systems of verifying the credentials. A procedure for digital rights certification will essentially mandate the decision of agent *a,* whether to respond to a request or not, and in case it will, to decide how detailed this response should be (in terms of resolution, frequency, scale, units, etc). Such kind of negotiation among the peers within a virtual enterprise can resolve issues of data ownership, so that dissemination can be modularized, follow some rules, instead of the common situation of obscuring environmental data.

DISCUSSION

Related Work

A couple of applications reported in the literature drive towards the direction of virtual enterprises for environment information integration, management and sharing. For example, environmental data exchange network for inland water (EDEN-IW) aims to provide citizens, researchers and other users with existing inland water data, acting as a one-stop-shop (Felluga, Gauthier, Genesh, Haastrup, Neophytou, & Poslad, 2003). EDEN-IW exploits the technological infrastructure of Infosleuth system (Nodine, Fowler, Ksiezyk, Perry, Taylor, & Unruh, 2000; Pitts & Fowler, 2001), in which software agents execute data management activities and interpret user queries on a set of distributed and heterogeneous databases. Also, InfoSleuth agents collaborate for retrieving data and homogenizing queries, using a common ontology that describes the application field.

A quite analogous system that uses software agents for accessing environmental data is New Zealand distributed information system (NZDIS). NZDIS (Cranefield & Purvis, 2001, Purvis, Cranefield, Ward, Nowostawski, Carter, & Bush, 2003) has been designed for managing environmental metadata in order to service queries to heterogeneous data sources.

The Australian Bureau of Meteorology reports (Dance, Gorman, Padgham, & Winikoff, 2003) the development of forecast streamlining and enhancement project (FSEP), where agents are utilized for detecting and using data and services available in open, distributed environment. In FSEP agents manage weather monitoring and forecasts data.

Efforts towards the use of distributed architectures for environmental data integration and service provision have been given in the followings work also:

- **The Bremen University semantic translator for enhanced retrieval (BUSTER):** Utilizes ontologies for retrieving information sources and semantic translation into the desired format (Neumann, Schuster, Stuckenschmidt, Visser, & Vögele, 2001); BUSTER prototype is to be redesigned using software agents
- **The multi-agents-based diagnostic data acquisition and management in complex systems (MAGIC):** Even if it does not target only environmental applications, its objective is to develop a flexible multi-agent architecture for the diagnosis of progressively created faults in complex systems, by adopting different diagnostic methods in parallel. MAGIC has been demonstrated in an automatic industrial control application (Köppen-Seliger, Ding, & Frank, 2001). A similar application, developed by the same team is the DIstributed Architecture for MONitoring and Diagnosis (DIAMOND) architecture, which adopts an agent-based architecture for distributed monitoring and diagnosis (Albert, Laengle, Woern, Capobianco, & Brighenti, 2003). DIAMOND will be demonstrated for monitoring of the water-steam cycle of a coal fire power plant.
- **The Rilevamento dati Ambientali con Interfaccia DECT (RAID):** This system deals with pollution monitoring and control in indoors environments. *RAID* exploits the general architecture of *Kaleidoscope* that uses "entities" for the dynamic integration of sensor (Micucci, 2002).

Towards the direction of virtual enterprises for the environmental sector fall our prior experiences in developing environmental information management systems in distributed agent-based architectures. The O_3RTAA system (Athanasiadis & Mitkas, 2004) utilizes a community of intelligent software agents for assessing urban air quality. O_3RTAA agents share a domain-ontology for capturing information from air quality monitoring sensors, assess air quality and ultimately disseminate alarms to the public. A follow-up generic middleware system called AMEIM (Athanasiadis, Solsbach, Mitkas, & Gómez, 2005) has been developed that enables a configurable community of software agents to adjust dynamically behavior by introducing new services dynamically, based on already existing ones.

Future Trends

Previous experiences in the above-mentioned applications give a clear indication that the technological infrastructure for realizing complex, distributed architectures that manage environmental data, are available. Building upon these experiences, this chapter proposed a virtual enterprise formulation that exploits a distributed, service-oriented architecture for efficient environmental data fusion. A new paradigm for future EMIS design and development is established. However, inborn properties of environmental information make things much harder in real world, large-scale implementations. The lack of standardization in environmental data management, or to rephrase it more precisely: the poor penetration of standards in the every day environmental data collection and management practices has already leaded to a Babel of environmental information. Sound and semantically consistent integration of these data is a critical requirement for knowledge sharing. Virtualization of environmental information is the mean for overcoming problems (as those mentioned previously), but also for maximizing reusability, open access and easy integration of environmental software services. Finally, the role of ontologies for environmental data annotation and modeling is essential in future work in virtual enterprises for the environmental sector.

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