# Space + Time: Interoperable IT Architecture for 4 Dimensional Scenarios

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**Abstract**
This paper focuses on the issue of the interoperability of components of information and communication systems (ICS) and proposes a new IT interoperability architecture. Special attention is drawn to ICS applicable to Emergency Management (EM) tasks. Interoperability requirements are also derived from the need to support all phases of EM.

ICS uses simplified models of relevant elements of reality. Situations are normally modeled using a single model which in most cases focuses on either the time or space domain (using simulation or geoprocessing tools). Distributed or combined approaches make use of more than one model which sometimes stem from different domains. Here, in order to overcome the limitations of proprietary solutions, efforts have been made to support interoperability among models and systems. Although being extensive and ambitious in and of themselves, these efforts have been limited to one domain (the Open GIS Consortium (OGC) for the space domain and the High Level Architecture (HLA) for the time domain).

Owing to the complexity of real-life EM situations, the proposed concept interprets the situations to be modeled as four-dimensional scenarios. Based on coherent management and support of the space and time domain, such a combined model can consist of interoperable geoprocessing, simulation and other components. The goal is to combine and extend current interoperability standards to a new cross-domain level. This paper describes the current status of this approach.

## 1. Introduction

Information Technology (IT) is a valuable tool for Emergency Management and can be applied in all phases of the Emergency Management Cycle. Typical application areas cover analysis, forecast, training, decision support, base-line information collection, and dissemination.

Numerous IT tools and IT systems exist that offer some special type of functionality for a specific application area, like dispersion simulations, remote sensing systems, and monitoring systems. All these tools operate on datasets that must be collected and maintained. Often the quality, accuracy and relevance of the underlying data is a key factor for the quality of the decision support generated. These datasets can be seen as different representations of the same part of reality that is to be modeled and analyzed (in military terms: the *ground truth*).

This paper is on how different tools and systems can share data and functionality based upon a common agreement (contract) on the representation of the modeled reality.This provides the basis for reusable, cooperating IT components which is generally seen as basis for more efficient IT systems management at lower costs.

### 1.1. Classic Approaches in the Time Domain

Due to the fact that dynamic processes are the root of the matter of Emergency Management, simulation technology that allows to model dynamics is one EM key technology. During runtime a virtual clock is generated by simulations that is managed according to a certain time management scheme (movement along the virtual time axis).

Unfortunately, there are nearly as many different time management schemes and implementations of them as simulations and simulation tools are in existence. In addition, the coordination and synchronization of multiple (virtual) clocks is a non-trivial task. And third, most simulations and simulation tools are not prepared to cooperate with other tools (lack of interfaces).

Eventually conventional – mostly poprietary – solutions including special types of simulations and time management schemes have limited the runtime cooperation of specific (EM) simulation components. No classic approach provides an open, standardized way of interconnecting heterogeneous simulations and simulation tools.

### 1.2. Classic Approaches in the Space Domain

Classical GIS are still monoliths, working on layer based two dimensional vector or raster data. Interactions between different GIS are still realized by loose coupling techniques. This means that different applications are linked only by data transfers based on a common file format [14]. The consequences are inconsistencies due to data and method redundancy, and information loss due to non-appropriate data exchange formats and data models. Completely integrated systems on top of a common data and method base are hard to find [2].

### 1.3. Classic Cross-Domain Approaches

As well as GIS-GIS interaction is still done by simple data exchange, the linkage of GIS and simulation systems is recently an issue of data transfer too. Typically GIS are only used to pre- and post-process the simulation data. In addition to the above mentioned redundancy problems recent GIS causes further problems by lacking a number of features desirable in the spatio-temporal domain. The most important shortcoming is the missing 3D- and 4D-support, which restricts the usage of current GIS significantly [1].

Several cross-domain applications based on a GIS-simulation-coupling have been developed, e.g. for Evacuation Planning [13]. None of these solutions, however, is based on a non-proprietary, standardized, open interface between the software components.

Therefore, Interoperability of Systems within the same domain or across different domains is a key issue to be addressed.

## 3. Interoperability

Interoperability is defined as *„the ability of two or more systems or components to exchange information and to use the information that has been exchanged*" (Institute of Electrical and Electronics Engineers IEEE) [8].

Obviously, this is achieved by adhering to standards: standards of communication, standards of data formats, standards of function calls etc. We consider this as the basic interoperability level. Above that, the next two sections give a closer look on interoperability of information systems regarding to the management of spatial and time information respectively.

### 3.1. Time Domain

Simulations (1) define their own virtual time and (2) implement their own way of time management (how, when and how far the time advances within the simulation) which is normally not communicated to the outside.

Interoperability Task No. 1 in the time domain is therefore the synchronization of the virtual clocks of different simulations that have to cooperate. A considerable number of non-trivial problems have to be solved here (e.g. prevention of deadlocks, enforcement of causality (so that no event can influence its own past), etc.); for further explanation see e.g. [11] or one of the classic references [6].

Interoperability Task No. 2 is to ensure proper cooperation between the heterogeneous time management procedures. E.g., some will enforce strict causality by preventing non-guaranteed events from being processed until they become guaranteed while others allow their processing and, if causality is later breached, restore a previous valid state (optimistic approach). Nearly every simulation programmed in a high level language like C++ and every simulation tool has its own time management - this makes it, like Task No.1, also a non-trivial problem.

Distributed Simulation Technology addresses both tasks. In the past, numerous protocols and architectures has been developed, but none of them has addressed the interoperability tasks 1 and 2 in an equal, standardized way. The current state-of-the-art in Distributed Simulation Technology is the High Level Architecture for Modeling and Simulation (HLA) which was developed by the US DoD since 1996 and has matured since then to a NATO, DoD, IEEE standard and an OMG CORBA Facility [5].

HLA is based on a framework concept that relies on an infrastructure which manages data exchange and coordination / synchronization tasks (see figure 1). Instead of interfacing individual components with each other (left side of figure 1), each component needs only one (standardized) interface to the infrastructure in order to cooperate with all other components.

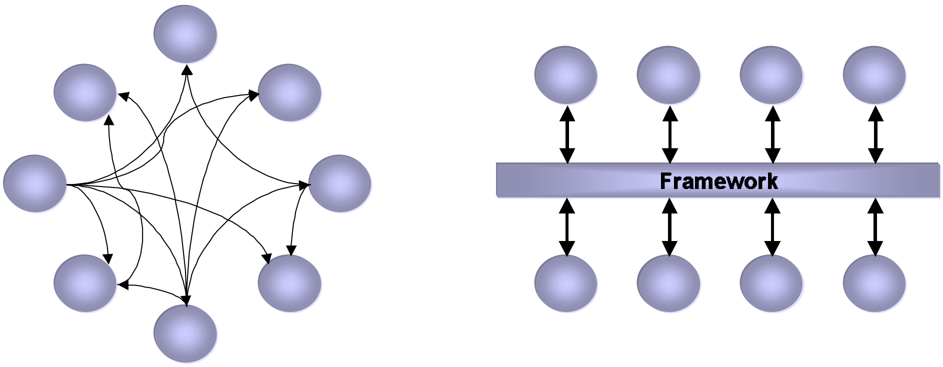


Figure 1: Classic versus Framework Approach

HLA is, although not perfect, the first technology to address and solve both interoperability tasks. The application potential of the HLA in the area of Emergency Management has been described already (see [15], [8], [9], [10]). In this paper, the HLA will serve as interoperability platform for the Time Domain.

### 3.2. Space Domain

Several interoperability initiatives exist in the geoprocessing (space) domain. The most promising activities in geoprocessing interoperability are those of the OpenGIS Consortium (OGC). The OGC was founded in 1994 and is driven by the most important GIS, Operating System (OS) and Database Management System (DBMS) developers, vendors and users. Its objective is to establish a global geoinformation infrastructure by developing unique service specifications. These specifications serve as a generic programming interface and allow interoperation of different GIS components [3]. Recently a number of data management and visualization services are completely specified. First commercial products are available.

In this paper, the OpenGIS specifications of the Open GIS Consortium (OGC) will serve as a interoperability platform for the Space Domain.

The prevailing specifications have two major shortcomings:

- Time isn't an issue yet.
- Even though it is essentially possible to start simulation processes, the accessibility of the results is restricted to only one for each call.

Therefore it is necessary to extend the current specifications regarding to the requirements of the space-time domain.

### 3.3. Space-Time Domain

Neither the classic approaches (refer to section 1) nor the interoperability initiatives described in the two previous sections allows the cooperation of time-based (simulation-based) and spatial information systems or components in a standardized manner. Therefore, the Space-Time Domain Interoperability is an open issue and will be addressed in the following sections based on the OGC specifications and the HLA (refer to sections 3.1. and 3.2.) as the state-of-the-art interoperability technologies in their respective domain.

Rather than embedding one approach into the other (which would render essential functionalities unusable in the other domain), we are following a tight-coupling-approach in order to generate added value for both domains without putting limitations to the original OGC / HLA architectures.

The following sections describes the OGC / HLA integration concept for interoperable, time- and space-based components.

## 4. Integration Concept and Software Architecture of Space and Time Components

The Open GIS Consortium (OGC) and the U.S. Defense Modeling and Simulation Office (DMSO) offer high performance standards for interoperable GI-services (OpenGIS) on the one and simulation components (HLA) on the other sides. Though both initiatives focus on complementary capabilities. We can find strong spatial capabilities in the geo information (GI) domain and strong time management capabilities in the simulation domain. Both worlds have to be integrated to facilitate proper modeling of spatio-temporal processes. A first technical integration approach will be presented in the following.

There are four major issues to be handled:

(1) Enabling the exchange of geoobjects between HLA federates

First of all we need an OMT compliant geoobject model describing basic OGC features (e.g. Simple Features, Simple Feature Collections and Coverages). Appropriate encoding and decoding factories will enable HLA federates to exchange OGC compliant geoobjects between each other. Standardized exchange implicates the use of the XML based Geo Markup Language (GML2) [4]. GML2 provides optimal de- and encoding capabilities to transform geoobjects into byte streams, the interchange format required typically by the HLA.

(2) Enabling the use of OGC services within Federates

Subclassing a HLA root federate by extending its capabilities to access existing well-known OpenGIS compliant web services results in the definition of *Geofederates* (see figure 2). Due to the fact that the current OpenGIS service specification lacks a common service interface to describe services generically, the implementation of a number of different interfaces becomes necessary. However, the outcome of the ongoing web map testbed 2 (WMT 2) [14], especially the upcoming basic service model will provide more generic solutions. The services' capabilities will be described by XML.

(3) Making Geofederates permanently accessible

Like other federates, *Geofederates* (GF) exist only during a simulation or monitoring process. Hence, contrary to common OGC Web Services, they aren't permanently accessible. This deficit is filled by defining a *GeofederateWebService* (GFWS), which is a web service that basically controls a *Geofederate* aggregation. It is permanently accessible and responsible for the initiation, controlling and destruction of *Geofederates*.

(4) Controlling distributed simulations

To control distributed simulations in terms of HLA federations it is necessary to offer *Simulation Controlling Services* (SCS) to start, control and destroy federations. This is done by communicating with the corresponding *GeoFederateWebServices* to access the required *Geofederates*. It offers a simulation scenario management and facade interfaces for an OGC compliant access, optionally a Web Feature Service interface or a Web Coverage Service interface. Extending the OGC specifications it will be necessary to provide data push mechanisms to allow a continuous data flow between the *Simulation Controlling Service* and any desired client. Once having the ability to describe the capabilities of an OpenGIS compliant service in a generic way, we are also able to specify interfaces that describe distributed HLA simulations as new OpenGIS services.

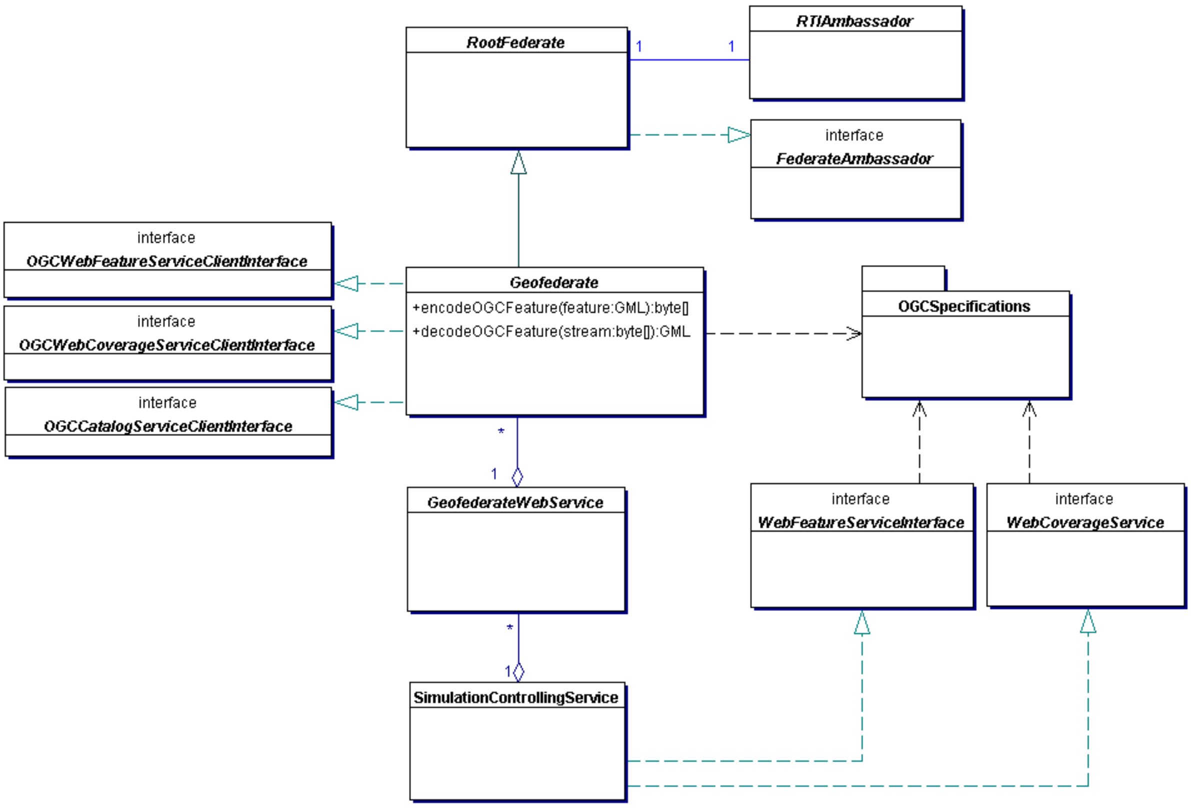


Figure 2: UML Class Diagram of HLA/OGC integration classes

But how to put things together? Based on a HTTP based communication bus – typically the WWW – we place OGC WMT 2 compliant Web services like Web Feature Services (WFS), Web Coverage Services (WCS) and Web Mapping Services (WMS) (see Figure 3).

Their interfaces are completely based on URL encoding techniques. We extend this architecture with *Simulation Controlling Services* (SCS), which are wrapped with OGC compliant interfaces to provide accessibility to simulation results (e.g. OGC Web Mapping Service). These Simulation controlling Services interact with *GeoFederateWebServices* (GFWS) which again instantiate *Geofederates* (GF).

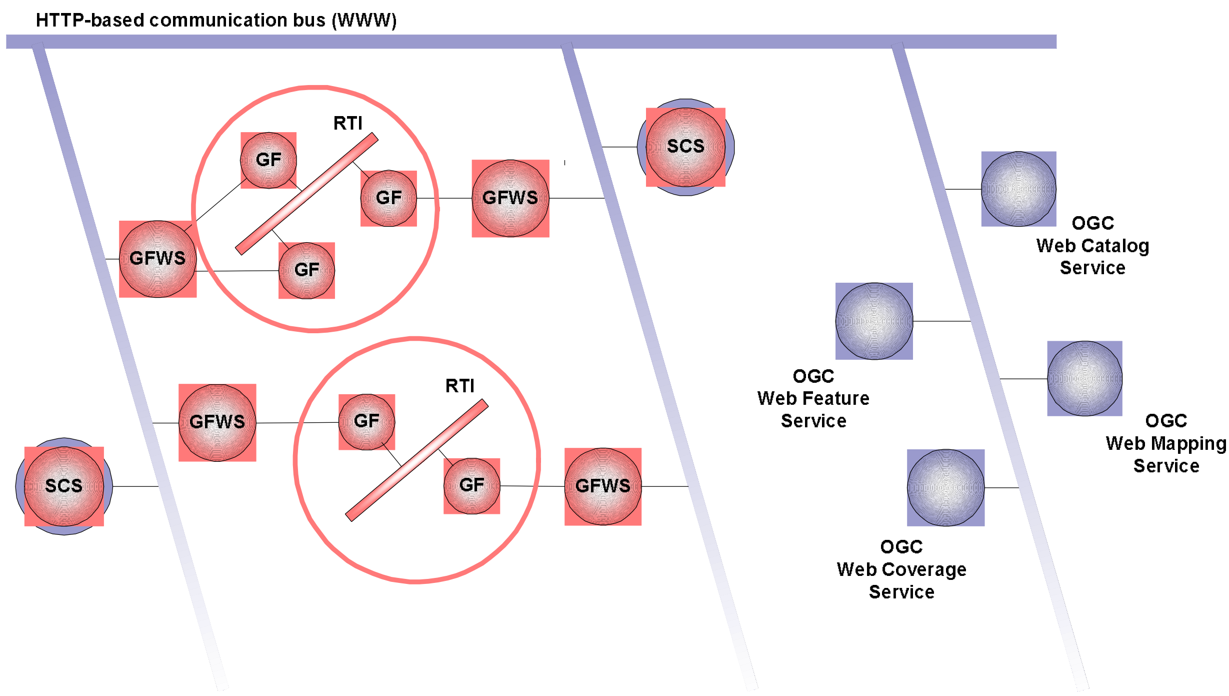


Figure 3: Integration Architecture

The communication and synchronization of the Geofederates is done by the RTI exclusively. Based on these elementary services it should be possible to specify a framework for spatio-temporal tasks.

## 5. Potential Applications in Emergency Management

The potential of this integration approach becomes particularly clear if the concept is applied to a complex EM simulation scenario. Consider an atmospheric dispersion model to simulate the hazards raised by an industrial accident. The site specific contamination risk in the surrounding area could be simulated based upon recent weather data (temperature, air pressure, main wind direction, precipitation, etc.). While permanently updated dispersion forecast acts as an input parameter for an emergency management tool optimised evacuation plans could be automatically generated and maintained. Simulations could directly use the geographic data of the place of incident without separate initialization. GIS components could be used as 4D user interfaces that allow the visualization, animation and comparison of different dynamic scenarios. Information about the effective traffic situation could be incorporated and permanently updated.

## 6. Conclusion and Outlook

In this paper we have described an approach for interoperability of time-based (e.g. simulation) and space-based (e.g. GIS) software components. Each component can benefit from the complementary functionality provided by other components of the same or the other domain. An integration concept based on the two state-of-the-art interoperability technologies (OGC for the space domain and HLA for the time domain) has been described. As the paper describes the current status of ongoing research it is expected to see prototypes and usage concepts, e.g. in the Emergency Management domain as a favorable application area in the near future.

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