Modeling Framework for Hazard Management Applied to Water Pollution and Radiation Dispersion

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Abstract— **Management of natural and industrial hazards is performed through cooperation of a multitude of actors, sometimes from different institutions sharing common objectives, which belong to virtual organizations responsible of monitoring risks and responding to emergency situations. The information systems dedicated to this domain are multidisciplinary, highly distributed, and characterized by the co-existence of physical and computational artifacts. The paper introduces a modeling framework for the description and development of hazard management systems, implemented for prediction, decision support and early warning. The framework is not dependent of any modeling language and it is applied here for the characterization and the comparative analysis of two platforms: one for accidental river pollution and the other for the propagation of radioactive clouds in case of nuclear plants incidents.**

Keywords—Information System; Software and Systems Modeling; Hazard Management

I. INTRODUCTION

Nowadays, due to climate change and intensification of unusual natural phenomena and industrial accidents, a new category of systems marks its presence, dedicated to all the phases of hazard management, from risk assessment to monitoring and response. Several approaches of system modeling are available in the scientific literature for this application domain or for similar ones. An architectural style for cyber-physical systems was proposed in [2], where one introduces software, hardware, physical and control views, and outlines that their correspondent models belong to multiple domains, therefore the challenge to establish proper relationships for integrating them into a coherent system. Meissen and Fuchs-Kittowski identified several architectural components that may be part of future reference architecture for Early Warning Systems (EWS), like: monitoring, hazard detection and warning systems [3]. They also designed an extended monitoring capability for crowdsourcing, which is expected to integrate information from sensors, humans and other monitoring and information systems. The aspect of information logistics was conceptualized by Lendholt and Hammitzsch [4], who defined characteristics of the early warning messages, like their type – depending on the hazard attributes – or their recipient – registered to a dissemination channel and specifying a certain area of interest. They used the Common Alerting Protocol (CAP) standard for indicating the spatial reference and the criticality. Service-Oriented Architecture (SOA) was applied in [5] for an EWS framework that integrates factory and special data processing services distributed at European level, and respecting the models defined by the INSPIRE directive (http://inspire.jrc.ec.europa.eu).

The architecture of hazard management systems corresponds very well to the definition of enterprise architecture, i.e. it analyzes “areas of common activity within or between organizations, where information and other resources are exchanged to guide future states from an integrated viewpoint of strategy, business and technology” [1]. Based on this observation and inspired by the matrix classification schema of the Zachman framework [6], we defined a general modeling framework for the description and development of hazard management systems, called H-Geo. It describes the architecture of hazard warning systems, aiming at making the difference between common artifacts and those specific to the type of hazard involved.

Chapter II presents the context of hazard management systems. Chapter III introduces H-Geo and explains its three perspectives, useful for the main stakeholders of hazard warning systems: hazard-specific experts, emergency professionals and specialists in Geographical Information Systems (GIS). For each of them, the framework identifies typical computational and physical artifacts. Chapter IV applies the H-Geo modeling framework for describing and comparing two early warning systems concerned with water pollution and radiation dispersion caused by potential industrial accidents. Chapter V discusses several challenges related to the framework application and to the development of systems for hazard management in general.

II. HAZARD MANAGEMENT SYSTEMS

Natural and industrial hazards may cause unexpected and significant changes in our lives and in our environment. For mitigating risks and dealing with disasters effects, there is an increasing attention towards the development of cyberinfrastructures [7] for highly distributed monitoring of essential physical quantities, and automated identification of potential emergencies, for fastening the corrective response and controlling the system. The complexity of such systems is due to requirements like:

- Generation of large scale data that have to be processed in real time;
- Necessity to use numerous and sometimes expensive physical artifacts, like sensors, spectrometers, satellites;
- Severe time constraints for getting a successful feedback, composed on complex actions performed by various devices and humans, pertaining to multiple organizations and
- Necessity of a previously prepared coordination even in case of highly improbable events.

These issues can be addressed with high performance computing, automated execution of processes in case of crises situations, cross-boundary and cross-institutional collaboration, sophisticated mathematical models, multidisciplinary approaches, advanced visualization based on geographical information, collective awareness and inference engines for rapidly suggesting the best decisions.

Various hazard warning systems are implemented for each type of hazard; twenty types and more than a hundred systems were identified in [8]. They have a large variety of onset timing, from the climate change risks – for which the consequences can be visible in ten years, to earthquakes – where the control loop should last no more than several seconds for activating the protection of critical assets. There are also countries that are more often affected by disasters, many of them characterized by a low income, especially in Asia, where very high mortality and economic damages were reported [9]. Therefore, a solution that is currently promoted is to realize multi-hazard systems, where generic components, like map visualization, may be reused. This is also a necessity because an initial event may induce multiple effects; for example, the disaster from Fukushima Daiichi was initially caused by an earthquake, followed by a tsunami that led to a hazard from the category of industrial accidents, with immediate consequences of water, air and ground pollution in the proximity of the plant, but also a potential threat of pollution at long distance, including other countries and continents, due to the movement of clouds containing radio-active isotopes, as well as the dispersion of the contaminated water.

III. MODELING FRAMEWORK

Our work on developing cyberinfrastructures for planning the reaction to water pollution and radiation dispersion, as well as the study of several attempts to identify reference architectural elements described in the scientific literature, led us to the definition of H-Geo – a modeling framework built on 3 perspectives and 2 views. The framework, including the types of stakeholders and the views, is illustrated in Fig. 1. Note that H-Geo has the form of a matrix, similarly to the Zachman's structure for enterprise architecture [6], and also to other related frameworks, like The Open Group Architecture Framework (TOGAF) [10] and Treasury Enterprise Architecture Framework (TEAF) [11].

A. H-Geo Perspectives and Views

The H-Geo framework describes the system from the perspectives of 3 types of stakeholders: *Hazard-Specific Expert, Emergency Professional* and *GIS Specialist.* A stakeholder may belong to the state government, to industry associations, NGOs (Non-Governmental Organizations) or to various businesses, because hazard warning systems may be implemented by a consortium composed of multiple organizations.

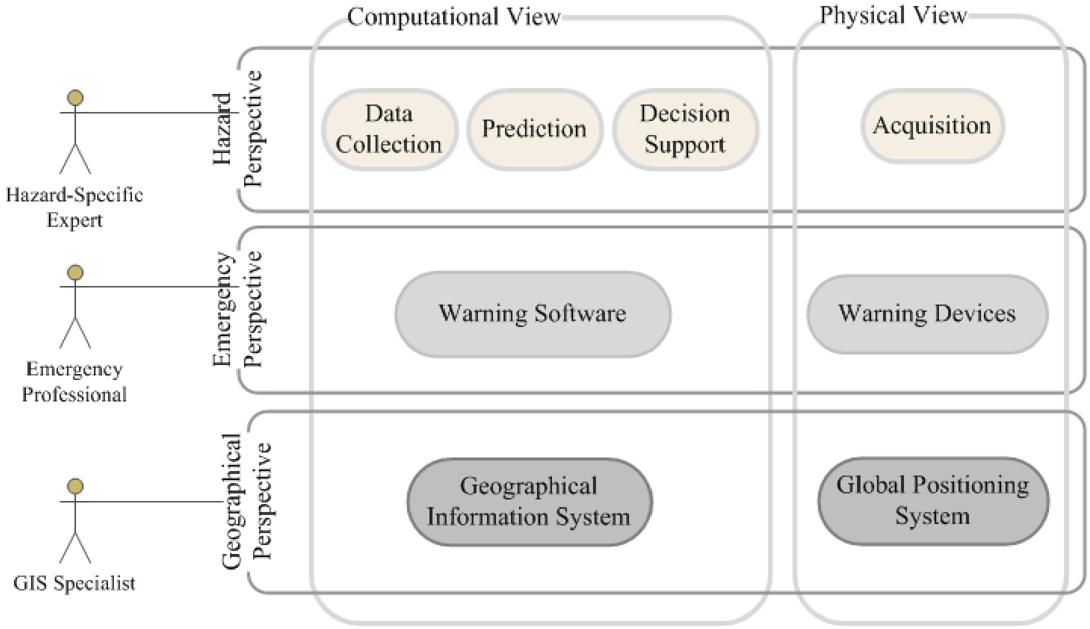

Fig. 1. H-Geo Modeling Framework

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The *Hazard Perspective* represents the concerns of a *Hazard-Specific Expert*, who may be a hydrologist, a nuclear physicist, a meteorologist, a specialist in geophysics, or a chemist.

The *Emergency Perspective* is that of the *Emergency Professional*, who may be a paramedic, a fireman, a policeman, a physician, a psychologist, a mayor etc.

The *Geospatial Perspective* corresponds to the *GIS Specialist* in areas like geography, environmental engineering, geosciences, geodesy and geo-information.

Each of the three perspectives may be described according to 2 views, making the difference between computational and physical aspects available for the correspondent stakeholders.

The *Computational View* models the software architecture, composed of various program modules, components or services.

The *Physical View* consists of physical devices like computers, sensors, measuring systems, mobile devices, telecommunication networks.

B. H-Geo Description

This section describes the software artifacts that correspond to the H-Geo matrix cells and are situated at the intersection of a perspective with a view.

The *Warning Software* consists in programs implemented for transmitting notifications to *Emergency Professionals*; it may also realize message and communication models, as well as interactions between various actors.

The *Warning Devices* artifact is identified as the physical view necessary for deploying highly distributed *Warning Software* pertaining the same H-Geo perspective; they may concern mobile devices, phones, but also other classical gadgets like flags, fires, or speaking-tubes.

The *Geographical Information System* corresponds to the computational view required by *GIS specialists* for data analysis and interactive visualization; it offers functionality for creating a collection of multi-layered maps, where one overlaps data specific to the hazard, based on geo-referencing facilities; recently, it also includes web services and various configurable data models.

The *Global Positioning System* represents the physical view correspondent to *GIS* and delivered by external accredited suppliers.

The *Data Collection* artifact is composed of non-homogeneous elements with diverse complexity, from simple files to entire information systems that originate data about the hazard of interest, like meteorological services or public websites of governmental organizations, who have to publish measurement results, statistics, reports, maps, or collections of historical data.

The *Prediction* architectural artifact contains data intensive applications for scientific computing based on mathematical models (e.g. for water or air propagation) which often need to estimate their parameters based on up-to-date values of physical quantities obtained from *Acquisition*, corresponding to multiple geo-locations given by the *Geographical Information System*.

The *Decision Support* concerns artifacts dedicated to risk and vulnerability assessment, artificial intelligence, rule-based engines and even critical process models.

C. Reuse Potential

Some of the architecture artifacts from the H-Geo matrix are specific to a particular hazard, i.e. those situated on the first row and related to the *Hazard Perspective*. The other artifacts, situated on the second and third rows, and dedicated to the *Emergency* and *Geographical Perspectives*, are generic and may be reused when developing hazard warning systems. Fig. 1 indicates the artifacts that are hazard-specific on a light background.

A system that integrates responses to multiple types of hazards should contain distinct architectural artifacts for each hazard that may be involved, and each of them should be designed, implemented and maintained by experts in the domain specific to the type of hazard, like meteorologists, hydrologists etc. However, the artifacts from the second and the third rows of the H-Geo matrix are highly reusable from one hazard management system to another, and they can also be considered for designing integrated systems to deliver warnings regarding a set of correlated hazards.

IV. FRAMEWORK APPLICATION

A. H-Geo for Water Pollution

The CyberWater system is dedicated to accidental water pollution - a hazard that affected our country (e.g. on Someş and Arieş rivers) – therefore, it has to be monitored on the watercourse segments of risk; the system stakeholders have expertise in hydrology and civil engineering, and the potential beneficiaries are national and river basin authorities [12]. The system is in the stage of validation with real data acquired from various observation points. Fig. 2 illustrates the CyberWater architectural artifacts, implemented for each matrix cell of the H-Geo framework.

The *Data Collection* is implemented with web services built with Windows Communication Foundation (WCF) and it is based on the translation to Sensor Observation System (SOS) standard. The data model is compliant to INSPIRE.

Data are originated from the *Acquisition* artifact, which is a Wireless Sensor Network (WSN), using National Instruments gateways and nodes for measuring: water discharge, temperature, conductivity, turbidity, pH and dissolved oxygen [13], as surrogate inputs of a mathematical model that may detect a potential water quality problem.

The *Prediction* is based on finite elements propagation models executed with MIKE, a simulation environment for hydrology [14].

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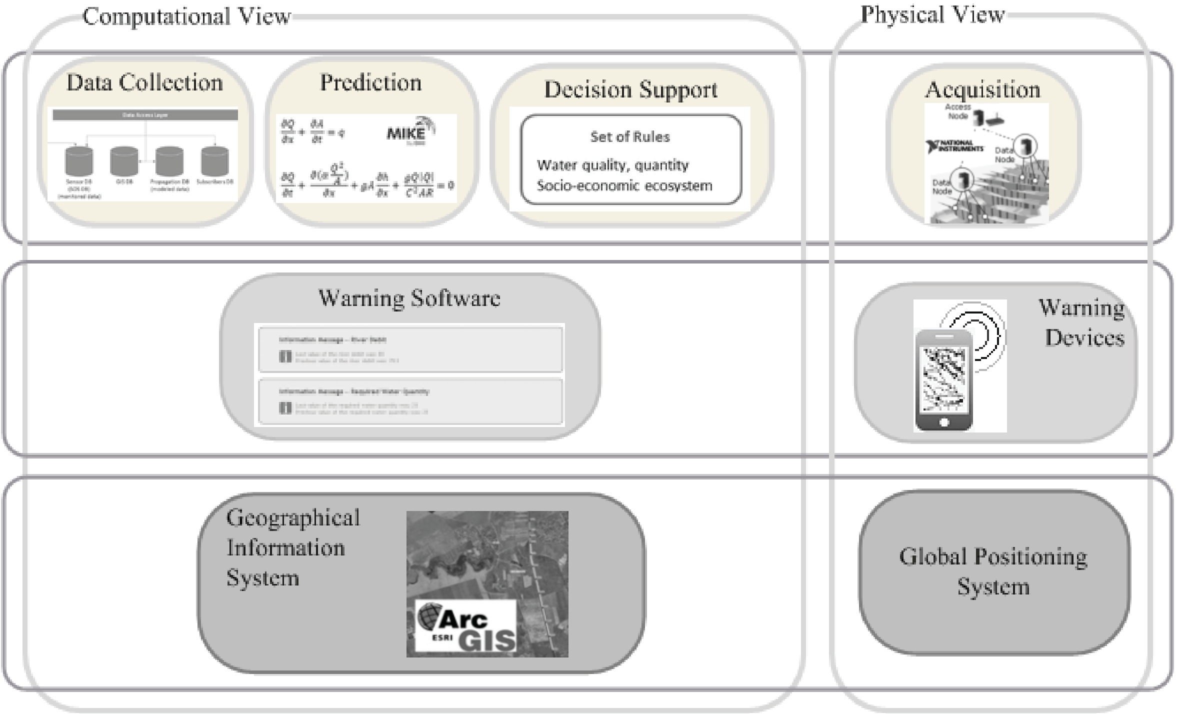

Fig. 2. H-Geo Modeling Framework Applied to the CyberWater Pollution Management System

The information is annotated with the geographical location, color-coded based on a system of rules and visualized on multi-layered maps [15] provided by ESRI ArcGIS and Google Maps, within the *Geographical Information System*. The *Warning Software* is programmed for MS Windows and Android operation systems.

B. *H-Geo for Radiation Dispersion*

The N-Watchdog system aims at realizing the anticipative assessment of fast dynamics of territorial vulnerabilities induced by nuclear facilities, including decision support for near- and far-field countermeasures that respect the Council of the European Union Directive 96/29/EURATOM [16]. The necessity of this system is due to the Cernavoda nuclear power plant, situated in the South-East of Romania. The system is in the stage of migrating the functional Proof-of-Concept (PoC) [17] – developed by the coordinating institution, specialized in nuclear physics – towards an industrial solution.

Similarly to CyberWater, N-Watchdog is related to the environment pollution caused by industrial accidents, and it targets the preparedness phase of emergency management; yet, their types of hazards are not similar and nor the physical laws that govern them. The risk is also very different, given the much lower probability and higher impact of nuclear incidents in respect with water pollution.

The *Data Collection* is built in N-Watchdog based on interactive web maps of nuclear emissions, and on forecasts available from meteorological websites, using web crawling followed by offline browsing.

The *Prediction* is based on mathematical modeling of radioactive emissions dispersion in the atmosphere, and the simulation of potential effects in the proximity of the radioactive source and at various distances; the system implements two Gaussian models: Puff Trails and Plume, the former applied for extended time and space scale, and the latter for the near-field.

The *Decision Support* is based on event trees and it has two components: the radiological assessment for up to 25 Km around the accident location, and the vulnerability assessment for up to hundreds of kilometers, evaluated by integrating static and dynamic indicators [18].

The *Warning Software* is deployed on a computer for the use of the emergency personnel, but a future version should also deliver warnings addressed to the large public.

The *Geographical Information System* is realized with geo-location services, using Google Maps API and Google Earth Plugin API, together with digital elevation maps.

C. *Comparative Analysis*

The comparative analysis of the two systems, presented in Table 1, follows the H-Geo types of architectural artifacts defined in Section III.

We notice that the inherent difference between the two systems is related to the *Hazard Perspective*, as indicated in the above description of the H-Geo framework.

For the *Computational View*, this difference stands in the ways of collecting data, i.e. integrating real-time measurements in CyberWater vs. mining data in N-Watchdog.

TABLE I. SYSTEMS COMPARISON BASED ON THE ARTIFACTS THAT REALIZE THE H-GEO ARCHITECTURAL FRAMEWORK

H-Geo Architectural Artifacts	**Systems**	
	CyberWater	***N-Watchdog***
Data Collection	WF C services	Web crawler plus offline browsing
Prediction	Hydrodynamic model based on finite elements	Gaussian Puff Trails and Gaussian Plume dispersion models
Decision Support	Rule-based C# component	Radiological and vulnerability assessment Event trees
Acquisition	NI Wireless Sensor Network	-
Warning Software	Alerts developed with ASP.NET MVC	Desktop application
Warning Devices	PC with MS Windows and mobile phone with Android OS	PC with MS Windows 7 or 8
Geographical Information System	ESRI ArcGIS and Google Maps	Google Maps / Earth

For the *Physical View*, it means a direct integration of sensor networks for determining water quality vs. an indirect access to measurement results through public websites.

V. CHALLENGES

The complexity and the interdependency of natural and industrial hazards determine the trend to integrate information and actions at a large scale. Still, the requirement of fast response can only be fulfilled by empowering and coordinating multiple stakeholders. This leads to concurrent objectives, which cannot be maximized at the same time. We identify here several challenges related to the implementation of architectural artifacts from the *Hazard Perspective* of the H-Geo framework.

A. Data Collection Challenges

The sources are highly non-homogeneous and crowdsourcing has become a necessity. Due to this variability of formats, data should be systematically transformed to respect standards, which are sometimes domain specific, in respect with the type of hazard. Apart from precise measurements, valuable information may also be extracted from social media, with participation of local communities.

B. Prediction Challenges

The algorithms often have to process Big Data, with the specific challenges regarding Volume, Variety and Velocity. The choice of the proper complexity of mathematical models strongly depends on the time scale characteristics of the hazard and on the potential efficacy of early warning. Prediction often needs a preparatory stage consisting of parameter estimation, configuration, modeling – before the real-time algorithms are executed, triggered by a particular event.

C. Decision Support Challenges

The decision alternatives should be adapted to the geo-location and to the available resources. They have to be obtained and understood quickly, requiring special visualization forms and pervasive notifications. The system of rules is often very complex and informally specified in text-based documentations, making the design quite difficult. Besides, the simple knowledge of rules is not enough, as the recommended response actions have to be assigned to the right stakeholder, in the right sequencing and at the right moment.

D. Acquisition Challenges

The physical artifacts used for acquiring data belong to different owners responsible of their maintenance. They have to be committed to their tasks and to be sure that consistent data are transmitted to the *Data Collection*. For instance, sensors have to be well integrated in the environment and sometimes they also have to be accepted (and protected) by humans, e.g. by local people; therefore, besides the technical aspects, increasing the awareness of the local communities is also important.

VI. CONCLUSION

The existing systems developed for managing various natural and human-originated hazards can be described in terms of perspectives and views, similarly to consecrated enterprise architecture. The paper introduced a modeling framework that identifies common types of architectural artifacts that characterize hazard warning systems, called H-Geo. It is organized as a matrix with three rows (associated to *Hazard-Specific Experts*, *Emergency Professionals* and *GIS Specialists*) and two columns (for *Computational* and *Physical Views*). Each cell of the matrix may be characterized by a set of architectural artifacts; eight types of artifacts were proposed in our framework, based on the experience of two research projects and on the study of scientific literature on early warning systems. The modeling framework was also applied for describing and comparing two hazard warning systems, for water pollution and radiation dispersion potentially caused by chemical spills into rivers, and nuclear accidents respectively.

Future work is oriented towards a more formal definition of the conceptual model of our framework, with a clear separation between semantics and abstract syntax. Given the current trend towards the development of integrated multi-hazard systems based on heterogeneous sources of data, the H-Geo modeling framework may also serve to the identification of general vs. hazard-specific artifacts, with the aim of identifying reusability patters. Inspired from consecrated frameworks for enterprise architecture, H-Geo can evolve towards a reference model for architecture planning in hazard management systems, with artifacts inherently distributed across several organizations.

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