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Ouejdane Mejri

Politecnico di Milano, Dipartimento di elettronica ed informazione, Italy, mejri@elet.polimi.it

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AN INFORMATION SYSTEM DESIGN FRAMEWORK FOR ENVIRONMENTAL RISK AND EMERGENCY MANAGEMENT

Mejri, Ouejdane, Politecnico di Milano, Dipartimento di elettronica ed informazione, Piazza Leonardo Da Vinci 32, 20133 Milano, Italy, mejri@elet.polimi.it

Abstract

Monitoring environmental risks for public safety applications (i.e. fire prediction, landslides forecasting, sea/river monitoring, etc.) requires an accurate model of involved phenomenological aspects, entities, actors, stakeholders as well as their articulated interactions. Due to the multidisciplinary nature of such scenarios several models are typically developed to address both concerns and information needs of heterogeneous skilled actors (e.g. geologists, geophysicists, chemists, managers, etc.), generally resulting in a fragmented process design. This paper goes in the opposite direction, i.e., we introduce a framework for designing collaborative processes for environmental risk and emergency management processes at multiple levels of detail. More specifically, through the use of UML models we provide a detailed description of "the system of systems" articulated scenario which proves to be effective in designing risk evaluation and assessment processes. The application case is that of the rock face collapse forecasting in the alps, where the hydrogeological risk affects urban areas implemented into a multidisciplinary research project, namely PROMETEO, that focused on civil and public protection. As further work we aim to describe the framework as an extension to the Unified Modeling Language (UML).

Keywords: Environmental process, Modelling, Framework, UML.

1 INTRODUCTION

Environmental risk assessment for emergency prevention and management is an issue that involves researchers in different classes of disciplines:

- Phenomenological experts (i.e. geology, geophysics, hydraulics, structural engineering, chemical and industrial risks, etc.) that study the critical phenomena to forecast (e.g. landslides, river floods, fire prediction and propagation, etc.) and develop hazard assessment models for both prediction and rescue/recovery procedures [17].
- Technological experts (i.e. digital processing systems, telecommunication and networking, software development, information systems and databases) that design and realize the technological infrastructure supporting the monitoring process and the emergency management phase [1].
- Organizational and cognitive experts (i.e. risk management, crisis prevention and management, crisis response) that focus on vulnerability and preparedness appraisal, in-crisis steering of critical infrastructures and post-emergency study for the development of sustainable responses to security paradigms [11].

Most crisis management tools and methodologies developed over the past 20 years deal with well-known risks that have local impact, i.e. actually no more valid for anticipating, detecting and clarifying the new hazards and to handle the escalation dynamics of their impact [18]. Nowadays crisis management for homeland security is faced to new kinds of crises where the risk is becoming more global and causing interdependent threats due to the domino effects (i.e. a cascade of events in which the consequences of a previous accident are increased by following one(s), spatially as well as temporally, leading to a major accident [4]).

Risk evaluation can be related to:

- Natural hazards: seismic, geological, hydrogeological, fire, etc.

- Technological hazards: transport accidents, industrial accidents (e.g. chain of events inside a plant, interactions among neighbor industries, events generated by the interaction between establishments and transport of dangerous substances), pollution, contamination, etc.

In this paper we will focus on environmental risk assessment processes that actually involve different classes of enabling technologies and define diverse dataflow management systems. It is common for these processes to be designed and implemented by different skilled actors as a number of small information systems each of which solves a portion of the problem [4]. Typically, these smaller systems are developed independently of one another presenting many forms of heterogeneity, creating many impediments to data integration and to maintaining a constant high level of quality of service.

This paper is structured as follows: the next section briefly reviews the literature and provides the context for our approach; section 3 presents the characteristics of environmental monitoring processes in order to identify their peculiarities respect to well-known and studied ones such as business processes. Section 4 firstly details the framework for adequate designing of high dynamic processes discussing the possible mapping between environmental monitoring process models and information systems models, then identifies the particular needs of such collaborative processes to achieve constant quality of service and proposes a discussion over the extension of UML models. Finally section 6 sets out our conclusions and work directions.

2 BACKGROUND AND CONTEXT

The physical phenomena as water body floods, seism and landslides are highly complex systems as they hold several unknowns and uncertainties due to the incomplete understanding of the phenomenological processes, to scaling aspects and to the high variability of their characteristics in time and space. The use of adaptive approaches was discussed and highly recommended in the geophysical communities [10] in order to join monitoring and modeling efforts in implementing efficient environmental monitoring systems. Researchers and practitioners brought to elaborate on natural phenomenon studies accorded that it is possible to bridge some of the gaps between research and practice and between different disciplines by adopting adequate modeling support [5].

An environmental monitoring process is typically compound of five principal phases that are executed either sequentially or concurrently (see figure 1), i.e. the identification of a critical phenomena to forecast and definition of aspects to be monitored, the data acquisition, the data analysis, the definition of characterization models (physical or parametrical models) and finally the application of the adequate identified model to evaluate local or global environmental risk.

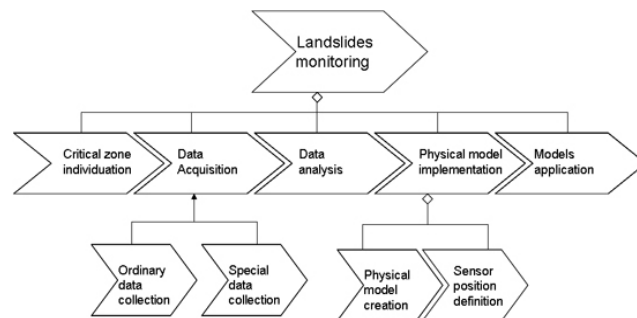


Figure 1. Environmental monitoring process composition: landslides monitoring case study

Actually the models used during environmental monitoring processes design consist in characterization models that aggregate the phenomenological parameters and permit to evaluate the risk properties (nature, probability of occurrence, risk level and potential consequences) [17]. As these models are event-specific, in large monitoring processes, distinct models are frequently coexisting (e.g. chemical, biological, geological, hydrological, etc.) and they are only used during the concluding phase of the monitoring process. Furthermore, the effort of model integration is generally unfeasible because of the diversity of competences of the experts and to the lack of “unifying modeling language”. A lack of design models for the entire process life-cycle is evident.

In the literature, a huge amount of models and methods were developed for the Information Systems (IS) design and successively for Business Process Modeling (BPM). Generic models with possible customizations were introduced for representing design process paradigms [16]. More particularly, business processes were designed from their different modeling perspectives (i.e. functional, behavioral, organizational and informational) using flowcharting, IDEF0, IDEF3, Petri nets, System Dynamics, Knowledge-based techniques, role Activity Diagrams, Activity based costing, Business Process Simulation and an extension of UML for BPM [15].

The widespread use of simulation modeling supports in risk assessment processes design as well as in business process modeling demonstrates the importance of dynamic models for evaluating such processes. The visual interactive features of simulation packages allow multidisciplinary team members to understand the model and to communicate about it [8] in BPM, and to evaluate different alternatives between future scenarios or detect some possible failures in present ones in environmental monitoring domain [11]. More particularly, Petri nets have attracted much interest as a potential formalism for modeling manufacturing systems especially instead of the conversational state-charts of UML to obtain verifiable dynamic models [4].

3 ENVIRONMENTAL MONITORING PROCESSES

The risk assessment and management process is compound of two principle sub-processes, namely the monitoring process and the emergency management process. These two processes are highly related as shown in figure 2 since they are associated to the same hazard, they rather involve the same actors, the output of the former is an input of the latter and they may have a constant information exchange during the crisis contingency (see figure 3). In the subsections that follow, the landslides monitoring case study will be introduced. The description of the environmental monitoring processes characteristics will be detailed in sections 3.2 and 3.3.



Figure 2. risk assessment and management process composition

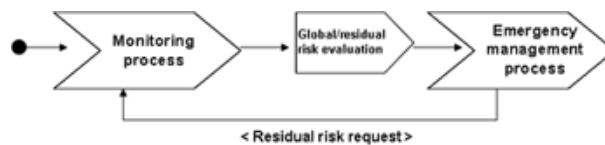


Figure 3. sub-processes synchronization

3.1 Landslides monitoring case study

The application case is that of the rock face collapse forecasting in the alps, where the hydrogeological risk affects urban areas implemented into a multidisciplinary research project, namely PROMETEO, that focused on civil and public protection. During the design phase of the environmental monitoring infrastructures several research areas were involved, i.e. embedded systems, software design, data communications, data analysis and management. One of the developed models during this step is a hardware deployment diagram shown in figure 4. The proposed hardware architecture for the case study is designed as a tiered architecture composed of sensor nodes acquiring the application-specific information and a network gateway which collects data and forwards them to a control room base station with a remote transmission radio. The diagram in figure 4 describes the hardware resources needed for the monitoring infrastructure but does not clarify the data flow, the activities to be done, the actors involved and the dynamic states of the architecture.

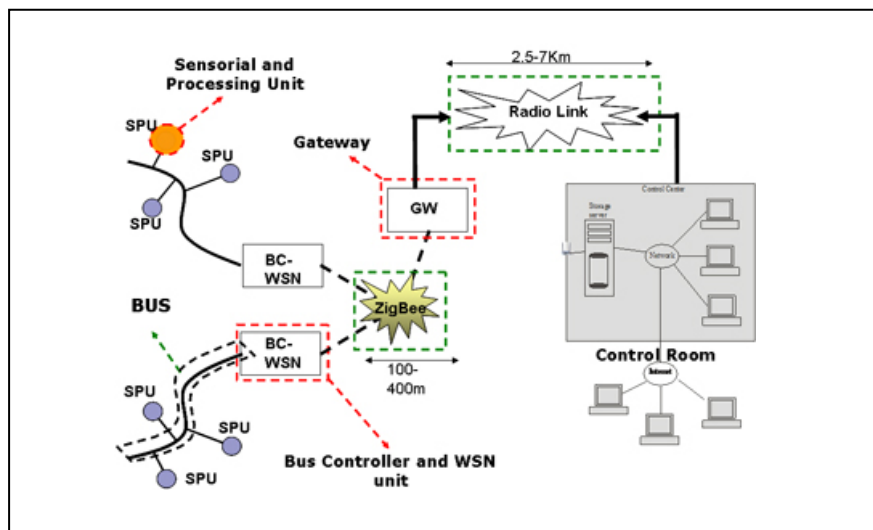


Figure 4. Hardware system architecture for landslides monitoring

The data used in such process is distributed, shared by different actors, activities and processes. It defines both topological and computational process complexities. Initially, the data acquired by the sensor networks (i.e. geophysical signals and events) has to be calibrated, eventually regularized and adequately memorized in temporary buffers and then in adequate databases. Therefore, it will be extracted, analyzed and aggregated into physical or parametrical models in order to forecast possible rock falls or landslides. This particular dataflow description has to be adequately designed and its characteristics (i.e. properties and constraints) defined in order to be evaluated by the process users. During the design phase an entity-relationship model was proposed for the database structure design but this model was not integrated with others. In this section, we only refer to the information system requirements not including the phenomenological and probabilistic models that have been developed i.e. numerical model of the cliff, 3D geometry of potentially unstable blocks and Bayesian Belief Networks (BBN).

3.2 Environmental process modeling

Process modeling is considered a key issue by the software engineering, information systems engineering and business process modeling communities. As described in section 3.1, the main particularity of environmental risk assessment processes consists of their heterogeneous composition: information systems are combined with “business” aspects and phenomenological models. In fact, information systems support the activities of the entire process and are embedded in the phenomenon study and analysis (i.e. sensor networks, data transmission, storage, extraction, aggregation and visualization). Furthermore, business and environmental processes have several common components i.e. processes, activities, entities, resources and goals [3]. In fact, environmental monitoring processes are decomposed in single coordinated activities that may be performed by human actors or automatic devices, have to achieve pre-defined goals and use particular resources. Each process uses a set of inputs in order to complete its activities and results in a set of outputs that describes the process termination state.

3.3 Process peculiarities

At variance with the business processes that are generally stationary, the environmental monitoring processes are mostly non-stationary. On one hand, the monitored phenomenon (i.e. natural) evolves over time modifying the stochastic characteristics of the data collected through the acquisition process. On the other hand, the technology used for collecting such data is also dynamic since sensor networks architecture may be reconfigured during their lifecycle [1]. This fundamental property has to be considered during the process design phase by introducing and defining the appropriate constructs that permit to represent the process constraints and to allow the fulfillment of its main goal, i.e. assure a constant quality of service during the execution of the process activities.

4 DESIGN FRAMEWORK

In this paper we present a modeling framework to derive monitoring processes models from UML models [2] identifying the potential mappings between respective modeling elements. For designing a “system of systems” as can be defined the environmental risk and emergency management process case study, we use UML activity diagrams and use-case diagrams to describe processes, activities, resources and user requirements. The design framework proposed in the following subsections permits to use on one hand the existing models of UML and on another hand to propose the definition of new constructs that suit with environmental process needs.

4.1 Mapping framework

Several models were developed for information systems modeling classified in *activity-oriented models*, *product-oriented models* and *decision-oriented models* [2] successively adapted for business processes that are directly coupled to information systems ones. More specifically, the Unified Modeling Language originally conceived as a general-purpose language for modeling software systems [2] was adequately extended for BPM [6] and used for business process simulation [3]. The UML defines a wide range of diagram types but in this paper we will only focus on activity and use case diagrams. This choice is due to the presence of required constructs in these diagrams for environmental process modeling as shown in table 1 and 2.

Activity Diagrams constructs	Environmental Process Elements
Activity Diagram	Process
Activity/set of activities	Activity/sub process
Swimlane	Actor (person, system, etc.)
Objects	Resources (physical, information, etc.)
Activity synchronisation	Activity flow execution (time)

Table 1: Mapping between activity diagrams and Environmental process elements

Using UML activity diagrams we can emphasize the flow of control from *activity* to activity to describe the behavior of the *actors* involved in the process, the collaborative sub-processes and their synchronization over time [2]. The *object* construct permits to represent the resources employed by each activity (i.e. sensor, transmission bridge, archive, database, document, etc.) in each sub-process. This representation allows characterizing a comprehensive architecture from the actor point of view illustrating to all the stakeholders *what* is performed, *when* and using *which* kind of support.

Use case Diagrams constructs	Environmental Process Elements
Use case Diagram	User requirements (IS, physical models, etc.)
Action	Process activity
Pre-condition/Post-condition	Process requirements/Process outputs
Actor	Actor (person, system, interface, etc.)
« include », «extend» and inheritance relationships	Whole-part hierarchies between sub-systems

Table 2: Mapping between use case diagrams and Environmental process elements

UML use case diagrams can be used to design stakeholder’s requirements for an environmental process where each diagram represents a part of the whole system architecture. The « include », «extend» and inheritance relationships allow representing how the sub-systems that compound the “system of systems”

are related and subsequently how they may be integrated. The pre-condition and post-condition constructs permit to express for each sub-system the needed inputs and the possible outputs (i.e. information, variable value, physical condition) in order to coordinate between heterogeneous data flows.

The dynamicity of the environmental process we deal with consists not only of state changes during the process execution in terms of activities, resources or actors that can be properly designed by the UML activity diagrams and use-cases. These processes are considered non-stationary according to two distinct aspects:

- The monitored phenomena (either under pre-alarm or emergency condition) can evolve and be described all through the process execution with different data or variables (e.g. a micro-acoustic signal may have different shapes during the monitoring phase requiring the activation of different flow of control of data treatment activities). In the design phase of a monitoring process we have also to take into account the fact that data structure can be dynamic and that an activity or a sub-system can access to one or other kind of data or may be employed regarding the scenario enacted.
- The technological architecture can mutate all over the process life-cycle, e.g. a sensor may switch off due to a robustness fault or lack of energy causing a transient or permanent topological changes in the sensor network architecture. This fact has to be faced during the process design phase since the reconfiguration of a part of the information system implies the reconfiguration of the following process elements:
 - Activities: during the process execution some activities may be interrupted, eliminated, others may be introduced dynamically. The activities can be classified in compulsory, optional, continuous, interruptible and “perishable”. The reconfiguration of the activities in an activity diagram is possible using conditional flow of execution but the UML diagrams semantics do not cover all these features like interruption or elimination.
 - Objects: changes in the technological architecture cause the use of one or another type of object by the process activities. Adequate labels have to be used to describe the object state according to the sub-system to which it belongs. The use of class diagrams is useful for the representation of physical or information sub-systems architecture but we need to introduce new features to describe the quality constraints in terms of conditions on compulsory/optional/interchangeable objects.
 - Actors: human actors involved in a monitoring and emergency management process may change in terms of hierarchical roles, responsibilities, accessible data, decisional freedom degree and consequently performed activities. This dynamicity has to be expressed through adequately adapted diagrams.

Furthermore, as the components of the process may change over time either at the conceptual or at the logical/physical level, these changes have to be effectively designed so as to guarantee a constant level of quality that may be expressed in constraints over the minimum number of activities, minimum number of technological objects, energy management, skills management, etc. These changes have to be handled as exceptions are dealt within a software design process to avoid error occurring and provide process fault tolerance.

5 CONCLUSIONS AND FURTHER WORK

In this paper we focused on the landslide monitoring process to illustrate a process design framework by discussing the main required elements and possible mapping constructs to existing design models. This framework has been formulated to support the following claims: (1) the environmental processes, information system processes and business processes share common properties (2) UML models offer constructs that permit to design a “system of systems” within normal conditions for an environmental process (3) UML diagrams offer elements that design a part of the dynamicity of such processes. Finally, we highlighted the designer needs to introduce new constructs that permit to describe peculiar environmental monitoring processes properties such as data and process non-stationarity. As further work we aim to describe the framework as an extension to the Unified Modeling Language (UML) and to consider the emergency management process design as the next process to analyse.

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