

Sapateiro, C., P. Antunes, G. Zurita, R. Vogt and N. Baloian (2008) Evaluating a Mobile Emergency Response System. Groupware: Design, Implementation, and Use. 14th International Workshop, CRIWG 2008, Omaha, US, September 2008 Proceedings. R. Briggs, P. Antunes, G. Vreede and A. Read, vol. 5411, pp. 121-134. Heidelberg, Springer-Verlag.

Evaluating a Mobile Emergency Response System

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Abstract. Existing information systems often lack support to crisis and emergency situations. In such scenarios, the involved actors often engage in ad hoc collaborations necessary to understand and respond to the emerging events. We propose a collaboration model and a prototype aiming to improve the consistency and effectiveness of emergent work activities. Our approach defends the requirement to construct *shared situation awareness* (SA). To support SA, we developed a collaborative artifact named *situation matrixes* (SM), which relates different *situation dimensions* (SD) of the crisis/emergency scenario. A method was also developed to construct and evaluate concrete SM and SD. This method was applied in two organizations' IT service desk teams, which often have to deal with emergency situations. The target organizations found our approach very relevant in organizing their response to emergencies.

1 Introduction

Information Systems (IS) development has been traditionally approached by focusing on predefined work models, most of them conceived with efficiency concerns. Nevertheless, many unknown variables, both external (e.g., market dynamics, natural disasters) and internal (e.g., latent problems, emergent work processes or the lack of flexibility in work structures), are among the factors that may lead to the lack of support of existing IS when facing unplanned/unpredicted/unstructured events. Such situations may often scale to crises, defined in [1] as a series of unexpected events causing uncertainty of action, or emergencies, when time-pressure is also present.

In non-routine or unique emergency situations, the use of anticipated protocols may be quite difficult or even impossible [2]. In order to adapt to a specific situation,

the involved participants rely heavily on their experience, and strategic decisions must be made often lacking full insight about the situation. Information shortage, as well as information overload, may lead to an unbalanced response (e.g., overloading some personnel, prioritizing less urgent actions, lack of awareness of mutually exclusive tasks).

Developing IS to support such unstructured scenarios raises several challenges, considering that work processes under such conditions are characterized by: having no best structure or sequence; often being distributed; dynamically evolving; unpredictable actors' roles; and unpredictable contexts [3]. These characteristics challenge the traditional IS assumptions regarding predictability and analyzability.

Our approach to IS support to emergency situations emphasizes the collaborative dimension of the emergency response rather than the more traditional command & control model [4]. The proposed collaboration model is grounded in several principles of resilience engineering. Resilience engineering is characterized as a comprehensive endeavor towards increased resistance and flexibility when dealing with the unexpected [5]. Resilience engineering should be regarded as an important and innovative approach to IS development, at least because the traditional IS approaches have revealed many limitations regarding emergency scenarios.

The main organizational failures addressing emergency situations, pointed out in [6], may be rooted in a lack of collective awareness of the ongoing situation. Our research contributes to the development of *shared situation awareness* (SA) as a mean to improve the emergency response. Our approach to SA relies upon a set of shared artifacts that may be collaboratively updated on a contingency basis. Considering that in many emergency scenarios the involved actors may need to operate in distributed locations, the approach is also based on mobile devices (tablet PCs and PDAs).

The prototype was developed on top of a pen-based application framework developed at the University of Chile. Besides handling all communication and collaboration issues, this framework provides a very rich collection of predefined pen-based gestures supporting the creation and manipulation of visual objects.

Aiming to evaluate our approach in real settings, we conducted experiments with two IT service desk teams operating in two different organizations. These teams often face situations classified as emergencies; for instance, if a network link or a server is down, it may compromise the organization's work. In a number of organizations, these situations are overcome without IS support.

One fundamental constraint of this research was the adoption of an adequate evaluation method. Groupware evaluation has raised many methodological concerns, since the adopted strategies may differ in: product maturity (design, prototype, finished product), time span (hours, weeks, months, years), setting (laboratory, work context), type of people involved (domain experts, final users, developers), and type of research (quantitative, qualitative) [7]. The scope of the evaluation process may also target different dimensions, ranging from the technical dimension (e.g., interoperability, connectivity) to the organizational dimension (e.g., effects on tasks performance, processes structure) [8, 9]. Concerning our objectives, several dimensions could have been considered:

1. Evaluate the collaboration model, including its capability to address emergency situations and incorporate the resilience engineering principles.
2. Evaluate the situation awareness hypothesis, aiming to improve performance in emergency response scenarios, thus focusing on the shared artifacts.
3. Evaluate the prototype usability.
4. Evaluate the technological constraints and its implications to performance (e.g., mobile ad hoc network - MANET issues).

Of course these dimensions are highly interdependent, thus increasing the difficulties accomplishing a comprehensive evaluation. Considering these difficulties, we established the reasonable goal to only evaluate the first two dimensions.

In the next section we present some research contributing to this work. Section 3 describes our conceptual approach. The prototype is briefly described in section 4. Sections 5 and 6 present the details of the evaluation process and the obtained results. We conclude the paper by making some remarks and pointing some future work directions.

2 Related Work

We may find in the research literature several projects addressing how to bring IS operations back to model behavior after deviations caused by unpredicted events [10-12]. The problem addressed by this paper moves the research beyond this perspective towards the support to emergent work structures in emergency situations, adopting a perspective where work models do not serve to prescribe work processes but rather as informational artifacts [13, 14] helping getting the work done.

Several definitions for SA may be found in the research literature typically referring SA as an understanding of the situation elements (people, objects, etc.) and dynamics (interactions, events, etc.) One of the most established models organizes SA in three levels [15]:

1. Perception produces Level-1 SA: the most basic level of SA, providing awareness of the multiple situational elements (objects, events, people, systems, environmental factors) and their current states (locations, conditions, modes, actions).
2. Comprehension produces Level-2 SA: an understanding of the overall meaning of the perceived elements.
3. Projection produces Level-3 SA: awareness of the likely evolution of the situation and possible/probable future states and events.

The recent research on *team shared awareness* highlights that teams need to detect cues, remember, reason, plan, solve problems, acquire knowledge, and make decisions as an integrated and coordinated unit [16]. The research on SA in the Computer Supported Cooperative Work (CSCW) field has developed a functional perspective of SA [17-20]. In our research we emphasize the organizational perspective, considering the orchestration of activities necessary to construct, manage and use SA. In this regard, the team members should not only be able to monitor and analyze SA, but also anticipate the SA needs of their colleagues. Hence, [21] define team SA as SA plus the mutual adjustment of one and another's minds as they interact as a team in a specific context of action.

We also adopted the phenomenological perspective of *contexts of action*, traditionally used in social sciences, which regards SA as evolving dynamically as actions unfold [22]. From an organizational perspective, this means that situated decision making models such as the *garbage can* [23] are more applicable to our context than traditional *rational choice* models [24].

Regarding the support to mobility, several collaborative solutions have already been proposed [25-29]. Although these proposals have shown useful to support specific collaborative activities, they were not designed to address emergency management. Their reuse capability is therefore relatively small.

3 Conceptual Approach

As stated in [6], resilience is a function of the organization's awareness. IS should thus focus on providing SA as a mechanism for efficiently sharing and coordinating actions in emergency contexts.

SA implies an understanding of the entire operating environment and should be built by taking advantage on the experience of the involved participants. In our approach, we aim to facilitate the externalization of the user's experience and tacit knowledge, enhancing the individual contributions to the overall understanding of the situation (supporting the externalization knowledge flow referred by [30]). This deference to expertise is a fundamental resilience principle and is trained in programs like Crew Resource Management [31, 32] adopted by aviation and firefighter organizations.

Considering the Swiss-Cheese Accident Model [33], accidents occur when several organizational defense layers are transposed. In our model we address the emergency situation by collaboratively constructing layers of defense. Involved actors should be able to align and correlate different *situation dimensions* (SD) of the unfolding events and actions. We consider as samples of SD: involved actors, necessary actions, resources allocation, goals, etc. For a given application domain, an initial set of relevant dimensions may be adopted and later on dynamically redefined, as the unplanned situation unfolds.

The existing SD are correlated in an artifact named *situation matrixes* (SM), expressing existing relations among different dimension of the situation. Samples of SM are Actions-Actors, Actor-Allocated Resources, Goals-Actions, etc. Despite a possible starting set, SM may be dynamically defined. Our specific implementation of the SM was inspired by the perspective proposed in [34], which uses several types of matrixes to visualize qualitative data, for instance: concept cluster matrixes, empirical matrixes, and temporal or event driven matrixes.

The SD correlations are specified in the SM as circles, using different sizes and/or colors to express the perceived strengths of such relations. Several alternatives may be considered to express the semantic meaning of such correlations, but in our approach we leave the concrete semantics to be defined by the application domain experts. Figure 1 illustrates the proposed collaboration model and SM artifacts.

The SM artifacts accomplish several goals: support action planning and status reporting; and by providing a shared integrated representation (kind of real-time dashboard), implement a monitor/feedback mechanism. As the situation evolves, the

SD may include more items (e.g., more actors involved, more actions proposed), and new SD may be created and related in existing or new SM.

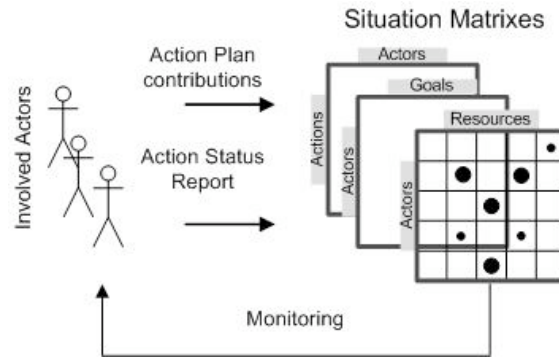


Fig. 1. Collaboration Model and SM artifacts.

4 Developed Prototype

As stated earlier, mobility may constitute a requirement in emergency management. The developed prototype operates in Tablet PCs and PDAs (see figure 2). The system is a full peer-to-peer application. This means that every user runs exactly the same application and shares data using the ad-hoc network. Using multicast messages, the application automatically finds other partners and establishes a reliable TCP link with them for transmitting data.

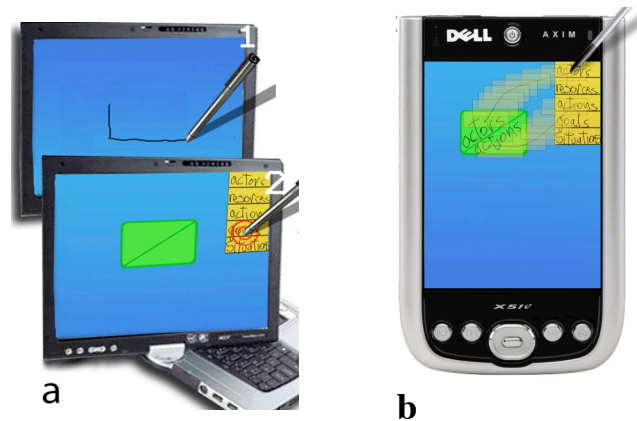


Fig. 2. Prototype a. Tablet PC b. PDA

A key concern while developing the prototype was requiring a minimal overhead to operate the SM. SM are easily created by drawing an half rectangle (figure 2a(1)).

The SM may be populated with SD as shown in figure 2b. To specify the contents of the matrix, it should be “expanded” by a double clicking on the rectangle. To create a new column, the user has to double click on the label of the columns (Figure 3a). After this, the user enters the header text for the column as shown in figure 3b. A similar procedure is used for editing rows (figure 3c).

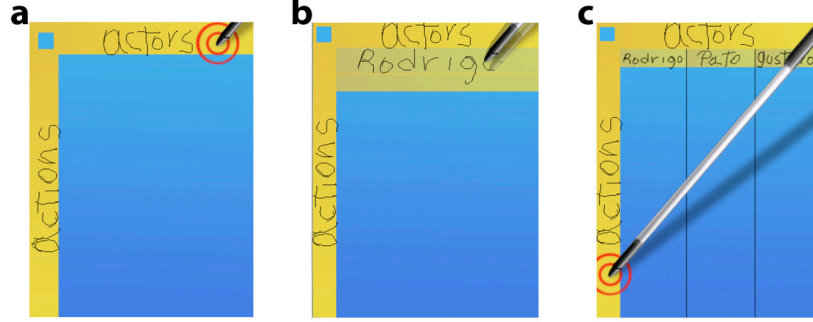


Fig. 3. Prototype a-b. Column creation c. Row creation

Figure 4a shows a user marking a relationship between SD items. This relationship is expressed with a dot of a certain dimension, with bigger dots meaning more importance. Figures 4b-c illustrates the navigation capabilities (scrolling and zooming) through the SM artifact.

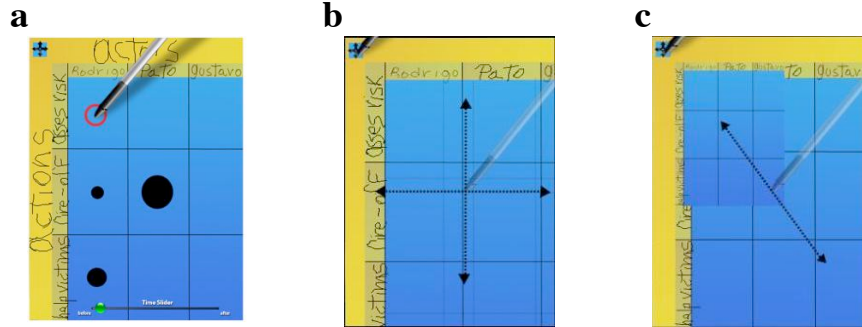


Fig. 4. a. Correlations editing; b. Navigation: Scrolling; c. Navigation: Zooming.

5 Evaluation

We have considered several alternatives to evaluate the collaboration model. Typical evaluation strategies include computer simulations, field methods and usability inspections. Although field methods allow capturing more realistic data, they could be difficult to settle in our case for several reasons: time investment, scenario setting, associated costs and prototype maturity.

The computer simulations allow, to some extent, to overcome some of these problems. We may find in the literature different approaches to computer simulations in our research context, from fully automated agent-based simulations [35] to hybrid approaches including humans in the loop [36]. Fully automated agent-based

simulations rely heavily on modeling (situation constrains, information flows, actors behaviors, etc.) A combination of computer simulations with humans in the loop may be accomplished with game playing in virtual scenarios. But despite the validity of these options, they all rely to some extent in pre-defined situations. Our work focuses on supporting human behavior in non-predicted scenarios, emerging in real time and from the involved actor's experience, which does not seem adequate to the computer simulation approach.

Usability inspection techniques are much less costly than field methods and they can often be used earlier and more frequently in the development cycle. However, since these techniques are not used in the actual work context, some researchers state that it is unclear whether the usability information they provide is valid for real-world contexts. In [37], the authors discuss that it is possible to integrate usability inspection techniques with work scenarios, jointly constructed by domain experts, and that these techniques may lead to results comparable to the ones obtained from field studies. We based our evaluation method in the combination of the inspection technique with the scenario based approach [38-40].

Our evaluation method consisted in four steps. We started by conducting a set of individual semi-structured interviews to IT service desk team members to present the problem and understand its relevance in the application domain. We also jointly analyzed a set of consequence scenarios aiming to understand which were considering realistic emergency situations and actual work practices. These interviews were audio recorded for future reference and analysis.

In the second evaluation step we administrated a questionnaire to each team member to identify the key requirements of collaboration support in emergency situations. The third evaluation step concerned the realization of a workshop (also filmed for future reference) with all team members, where we presented the collaboration model and a paper prototype. The paper prototype allowed focusing the evaluation on the model, discarding interference of possible usability and technological issues.

Table 1. Evaluation Methodology.

Step	Technique	Goals
1.	Semi-structured interviews (audio recorded)	<ul style="list-style-type: none"> • Introduce the support of unstructured activities problem. • Perceive the relevance of such problem in the IT service desk application domain. • Perceive actual emergency situations and work practices.
2.	Questionnaire 1	<ul style="list-style-type: none"> • Rate the set of proposed requirements to address unstructured work activities
3.	Workshop (filmed)	<ul style="list-style-type: none"> • Introduce the collaboration model and prototype. • Discuss its usage in a real scenario. • Collect possible SD and SM
4.	Questionnaire 2	<ul style="list-style-type: none"> • Evaluate the perceived effectiveness of the implementation of the collaboration model and prototype.

Once all participants were familiarized with this approach, we presented the prototype in more detail and discussed its usage. Finally, a second questionnaire was administrated to evaluate the perceived implementation of the discussed requirements; this constituted the fourth step of our evaluation. Table 1 outlines the various steps of the evaluation method and clarifies the respective goals.

Conducted interviews were structured around the topics summarized in table 2.

Table 2: Interviews structure.

Interviews - Discussed Topics	
1.	Which situations may be described as emergencies
2.	Current preventive practices
3.	Current diagnosis practices
4.	Current registration practices
5.	Current recovery formal procedures
6.	Current recovery informal procedures
7.	Current communication schemas
8.	Existing performance metrics
9.	Priority near future improvements (address current identified vulnerabilities)

Our evaluation method received several influences from different evaluation methodologies. From the groupware studies, we considered the heuristics proposed by the mechanics of collaboration [19, 37], which were developed to evaluate shared workspaces. Since our claims consider externalization of tacit knowledge and evaluation of team performance, we also considered the works from [41] and [42]. Finally, we also considered the situation awareness evaluation techniques proposed by [16]. The Table 3 summarizes the considered requirements for evaluation.

5.1 Conducted Experiments

In this section we present the outcomes of the experiments conducted in the two IT service desks. The experiments involved two teams of IT support in two different organizations. The first team was constituted by three senior and two junior members. The second team had the chief, one senior and one junior member.

We present bellow a brief summary of the main topics discussed in the interviews. Regarding the critical incidents, the most serious cases reported were related with server failures (in which the more frequent problem is the disk failure) and connectivity losses in some network segments (that may be due to switches' firmware problems) compromising a wide variety of services. It was also reported that more untypical problems may occur and lead to emergency situations, "[...] like a flood in the basement where some of the equipment is situated [...]" The existing preventive practices rely heavily in monitoring the active network elements trough a control panel fed by SNMP messages, where alerts are displayed and emailed to the technicians. Also, several equipments are under SLA agreements with suppliers and a spare stock exists. Actual diagnosis and recovery practices rely heavily in the field experience of each team member and the fact that they all know the intervention

domains of each one (e.g., some team members address Linux and others Windows problems).

Table 3: Requirements under evaluation.

Nº	Requirements	Influence Area
1.	Communication support through shared artifacts	Groupware Collaboration Heuristics
2.	Transitions between individual and team work	
3.	Coordination support	
4.	Facilitate in finding collaborators	
5.	Facilitate in establish context	
6.	Facilitate situation (specific issues) monitoring	
7.	Minimal overhead work demand	
8.	Mobile end device availability	
9.	Assist situation understanding	Situation Awareness
10.	Perceived who is involved	
11.	Assist situation size up	
12.	Assists (overall) situation representation	
13.	Knowledge externalization support	Knowledge Management
14.	Knowledge transfer support	
15.	Incident handling documentation	
16.	Improvement in diagnosis time	Performance
17.	Improvement in recovery time	
18.	Number of coupled incidents simultaneously attended	

The collaboration is essentially supported by meetings, phone calls and chat tools. Despite the existence of a trouble ticket software, it is only used (sometimes) for an incident opening and some (few) occasional post mortem annotations to close it. The reported main concerns regard documenting the intervention process, to facilitate future interventions and knowledge transfer. Considering these teams rely heavily upon experience, the junior members are often less performing. A number of other vulnerabilities were identified that could lead to critical situations; for instance, not all equipments have a spare stock or SLA coverage, and overcoming this situations is done by ad hoc measures and temporary workarounds that, once more, are highly informal and experience dependent. Also, the possible abandon of the team by a senior member may dramatically decrease the capacity to handle some incidents due to knowledge and collaboration losses.

In the second evaluation step, the IT service desk members answered to the first questionnaire, rating the relevance of several requirements to support unstructured work activities. The ratings were done in the scale: 1 - Not perceived as important, 2 - Less important, 3 - Important and 4 - Very important.

The questionnaire results yield that requirement 2 was not perceived as important. Requirements 12, 13 and 15 were rated from Less Important to Very Important. And all other requirements were rated either Important or Very Important. A more detailed analysis of the results in conjunction with the recorded interviews yield the following considerations: Knowledge transfer and incident documentation revealed Very Important to the team leaders; situation representation and knowledge externalization support revealed Important to the junior technicians.

Table 4, provides a description of the scenario collaboratively constructed in the workshops.

Table 4: Workshop scenario description.

Scenario
<p>“From several rooms, were reported the lost of network connectivity. Some technicians were notified by email, while others received several complaints by phone. The senior technician that received some of this complaints suspects from the central switch located on the main building.”</p> <p>How the proposed approach may help in coordinating, diagnosis and recovery actions?</p>

From the discussions that took place in both workshops, the highly informal and unstructured work practices were obvious to both teams. The courses of action vary according to the involved actors and some discussions took place on the more efficient ways to address this problem. A set of SD and respective SM were drafted in the paper prototypes. Figure 5 shows the paper prototypes used in the workshop sessions and the PDA prototype being operated.



Fig. 5. Prototype a. paper prototype b. PDA prototype.

Finally, the results from the last questionnaire confirmed that the proposed approach was perceived as aligned with the requirements that were considered relevant. But some further considerations are worth made: SM should be easily reused and a global representation of the situation (e.g., with all existing SD and which of them correlate) would be much appreciated. Regarding the implementation, some notes about navigating the existing SM were made to ease the use of correlations.

6 Discussion

It was possible to confirm in our experiments that, when facing emergency scenarios, the formalized procedures either do not exist or do not apply to the particular situations. The technicians' experience may dictate the set of actions necessary to inspect or recover some components, to involve specific actors with specific knowledge, etc. But many of these issues rely tacitly and distributedly on the team members, which constitutes an additional difficulty when coordinating their actions. At the end of each workshop both teams reported that these sessions revealed to them what they were already suspicious about: the individuals' tacit knowledge and experience strongly conditions the team's efficiency. The issue was not completely new and they were trying to address it by compiling a set of major guidelines to externalize and optimize the use of such knowledge. But due to the lack of time for this task, an interesting feature of the prototype would be to generate such knowledge from the correlations expressed in the SM.

Additionally, since the actions needed to overcome emergency situations may include several dislocations to different physical spaces/buildings, communication and mobility constitute key requirements to maintain shared SA among the distributed team.

As a result of the workshop sessions, a set of specific SD was proposed: Equipments, Actors, Locations, Actions and Activities, which should be correlated in the following suggested SM:

1. Actions-Steps, detailing operational activities (e.g., check router X, reboot switch Y).
2. Actors-Steps, defining responsibilities.
3. Equipment-Actors, expressing the persons responsible for the equipment (e.g., who is empowered to activate a supplier warranty, who is habilitated to inspect a Linux server or a specific service).
4. Equipments-Locations, allowing team members (mostly junior) to know the equipment locations (e.g., main gateway of building C6 is located in room 6.3.0.1).

Finally, regarding the evaluation method, some considerations are also worth made. The first interview revealed crucial to establish a common ground for a richer problem discussion. The paper prototype revealed a good choice to support the discussions about emergency scenarios. Since it did not constrain users regarding usability issues, it focused the discussions on: 1) the SD and SM necessary to address the emergency scenarios; 2) the semantic meanings of the elicited SM relations; and 3) the collaboration model to operate both SD and SM as shared artifacts.

7 Future Work

Besides addressing the various suggestions emerging from the evaluation process, we are also considering studying the timeliness of the situation awareness elements. Timeliness (recent, evolving, outdated, etc.) may be fundamental to further develop SA, since outdated information may considerably degrade SA. But the dependence on explicit user declarations constitutes an overhead work that should be, whenever possible, avoided. We are studying a pulling strategy to handle timeliness: 1) when users input information, a deadline is also introduced (e.g., valid for the next 15 min) and when this expires users are prompted to report information validity; 2) if no deadline is introduced, then the specified correlation will incrementally become more visually transparent as time goes by.

We are also exploring the integration of our approach with the IT Infrastructure Library (ITIL) framework in order to support other organizational levels involved in the different phases of the emergency life cycle management. To accommodate the required service levels and promote the IT infrastructure and business processes alignment, ITIL defines five processes: Incident Management, Problem Management, Configuration Management, Change Management, and Release Management. These processes are related with each other (e.g. incident management may fire a request for change – RFC handled under change management process responsibility) and share a set of ITIL objects (e.g. incidents, problems, RFCs). Our approach to SA regarding the collaborative editing of shared artifacts encompassing relations among situation entities could be extended to expose the relations among ITIL objects and processes tracking both functional and hierarchical escalation.

Acknowledgements. This paper was partially supported by: the Portuguese Foundation for Science and Technology, Project FCT (PTDC/EIA/67589/2006) and Fondecyt 1085010.

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