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Improving the Quality of Web-GIS Modularity with Aspects

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Abstract — **Spatial concerns of Web Geographical Information Systems (Web-GIS) are inherently crosscutting and volatile: crosscutting because they affect multiple functionalities of Web-GIS systems, such as visualization of a route in a map; volatile because their status may change often (e.g., in a map, a route can be obstructed temporarily due to a car accident or festivity, so alternative routes should be provided dynamically). The quality of Web-GIS services, in particular the efficiency required for their adaptation and evolution, can be compromised if volatility and the crosscutting nature of spatial concerns are not taken into consideration during modularization. This paper presents an aspect-oriented approach for Web-GIS applications. This approach models crosscutting spatial concerns and handles the volatile nature of some spatial concerns as if these were crosscutting. Thus, both types of concerns, crosscutting and volatile, are modeled as candidate aspects. By modularizing volatile concerns as aspects, it is simple to add and remove them at runtime from an application by using dynamic weaving. The approach starts with the identification and specification of crosscutting concerns and follows by composing them using MATA, an aspect-oriented modeling technique. GIS crosscutting concerns are stored and documented in a concern catalogue for promoting their reuse. Conflicts regarding the ordering of composition are also taken into account.**

Keywords – Web Geographical Information Systems, Aspect-Oriented Software Development

I. INTRODUCTION

In the domain of Web Geographical Information Systems (Web-GIS), spatial information is constantly added (even by final users). Additionally, new requirements, involving spatial functionality, emerge constantly and some of them are volatile, that is, they are only temporarily required. For example, some features are tested with users and eventually eliminated if they prove not to be frequently used. As a consequence, design tends to be more complex. An interesting example of this case is shown in Fig. 1 where we can see "Additional Information" to a photograph of Lisbon, on a Flickr home page[1]. This information, highlighted with a box in the page, shows the place where the picture was taken. (Geo-referencing of photos was originally added by users using GreaseMonkey[2] technology and later Flickr started to provide it as well.)

Adding new requirements into an application often becomes a hard task to the development team, especially when these new requirements introduce scattered and tangled code into the application, compromising the quality of the system's modularity. This results in an increased difficulty in software maintenance, evolution, and adaptability. A reasonable way to deal with this issue is to encapsulate scattered and tangled behaviors in separate modules using aspect-oriented techniques [8]. Hence, our goal is to use aspect-orientation to modularize tangled and scattered behaviors — that is, *crosscutting concerns* — in Web-GIS. Crosscutting concerns are later composed, or weaved, in different points, or joinpoints, of the same or other applications.

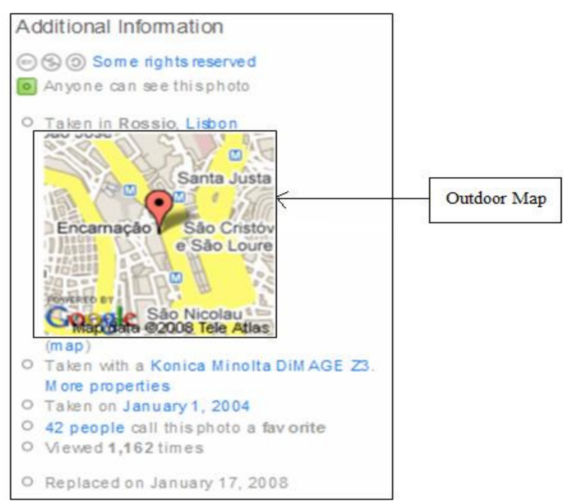

Fig. 1. Flickr page for a photograph with Outdoor map information.

The kind of concerns that we will address here is the spatial concerns, which are inherently crosscutting and volatile. To avoid these problems, we will therefore, use aspect-orientation,

[1] http://www.flickr.com/

[2] https://addons.mozilla.org/en-US/firefox/addon/748

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providing a better modularization mechanism to specify spatial concerns.

Typical crosscutting concerns arise when dealing with spatial data in Web Software (e.g., the user's location). The market increasing interest in mobile technology, associated with the need to improve applications that are able to consider the user's real position, becomes stronger every day. Web-GIS applications tend to be complex as they combine the volatile nature of Web software with the inherent complexity of dealing with spatial data. Moreover, from a software engineering perspective, location-aware behavior, typical of Web-GIS, usually cuts across other application concerns, since it is likely to have an impact across different application features [5, 17].

The approach proposed here is based on aspect-orientation and uses the MATA language [22] to specify aspects. We will demonstrate how spatial behavior can be isolated from other concerns to improve modularity in our application domain and, after having them modularized, how volatility is controlled in the composition phase by plugging and unplugging concerns. This work builds on initial ideas presented in a poster [19]. Here we explore those ideas further and propose solutions to contemplate the aspect interaction of spatial concerns.

The remaining of the paper is organized as follows. Section 2 presents a motivating example. Section 3 describes the background of our work. Section 4 introduces our approach. Section 5 applies it to a running example and discusses the results obtained. Section 6 discusses how an abstract and system-independent knowledge base can be built for Web GIS. Section 7 discusses advantages gained with the separation of GIS concerns. Section 8 presents related work and, finally, Section 9 draws some conclusions and describes future work.

II. MOTIVATING EXAMPLE

A typical new requirement which may be added to a Web GIS application is the "indoor representation". Fig. 2 shows a web application for a shopping centre[3] that provides Indoor Map support for presenting store locations. The application offers a "search function" to provide information about stores such as their address, their location inside the shopping centre (Indoor Position) — using the map pointed with a dashed ellipse. An Outdoor Map is also shown, indicating the location of the shopping centre in a global map. Both examples in Fig. 1 and Fig. 2 reveal how the same GIS requirements may be present in applications of different nature, contemplating many occurrences during one execution of the same application.

The inclusion of the new requirement "indoor representation" creates scattered and tangled concerns in the application among its core, or base, concerns. To make matters more difficult, adding other concerns increases the application complexity compromising its maintenance. (Section 4 describes how to deal with these new requirements in more detail and Section 5 illustrates some examples.)

Fig. 3 illustrates how the introduction of new requirements might impact the application's structure. This figure shows a UML sequence diagram for "Show Store". This is taken from the Web-GIS application Maps@Web [7]. It contains tangled behavior as a consequence of composing several GIS concerns such as Indoor Representation, Location Sensing and Points of Interest. We can see that the behavior of each requirement is scattered along the sequence diagram and tangled with other behavior, characterizing crosscutting situations. For example, Location-Aware crosscuts Indoor and Outdoor representations, due to the current user position, which can be either in a global map or in a specific building.

III. BACKGROUND

Modeling of Web-GIS generally involves the identification of requirements and system functionalities. It is of major importance to consider the modularization of crosscutting concerns in these applications, as it can be seen in [15, 24].

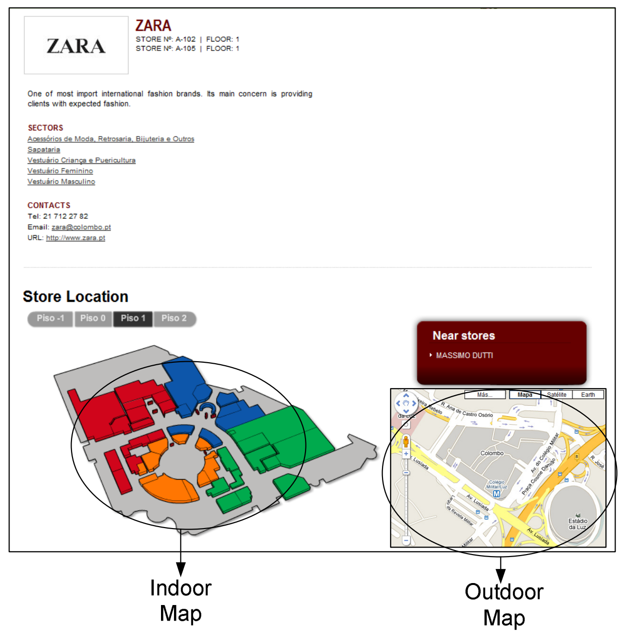

Fig. 2: A shopping portal with Indoor and Outdoor map support.

In this context, *aspects* were introduced to modularize *crosscutting concerns*, which could not be modularized using object-orientation [14]. Thus, crosscutting concerns are spread, or cut across, other concerns, creating tangled and scattered representations of the program that are difficult to understand and maintain [20]. Aspect-Oriented Software Development (AOSD) [8] appeared to handle crosscutting concerns in all stages of the software lifecycle. Aspects appeared first at the programming level, but currently they are used across the whole lifecycle. In particular, several Aspect-Oriented Requirements Engineering approaches have been proposed, such as [3, 16, 20], AORE with Use Cases [10, 11], Theme [1] and MATA [22]. Only MATA is described here, given both its high expressiveness [23] to model and compose crosscutting behavior, and because it uses graph rules which allow more composition possibilities and the identification of some aspect interactions.

[3] http://www.colombo.pt/

A. MATA

The MATA aspect-oriented modeling tool is based on UML, allowing aspects composition using class diagrams, sequence diagrams and state diagrams. Here we focus on MATA to model aspectual scenarios by using and adapting sequence diagrams. To specify aspectual scenarios, three new stereotypes where created to define composition rules:

- <<create>> which states that the element will be created in the base scenario
- <<delete>> which states that the element will be deleted of the base scenario
- <<context>> which states that the element will not be affected by the other two stereotypes

Variables in MATA are prefixed by a vertical bar "|", meaning that "|X" will match any model element with the same type of X.

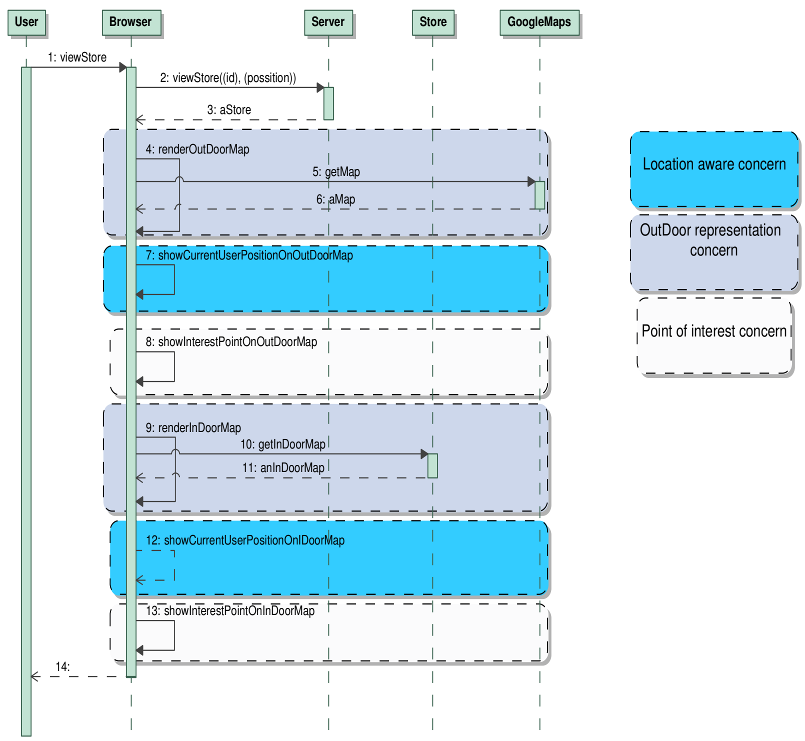

Fig. 3 Sequence diagram with tangled behavior due to crosscutting concerns.

After specifying both kinds of scenarios, base and aspectual, a pattern matching is made between them. This means that the MATA tool tries to establish a connection between elements of each scenario, always respecting the composition rules defined in the aspectual scenario. The resulting composed scenario describes the behavior of both scenarios, according to the rules defined. MATA allows more composition combinations than other existing aspect-oriented modeling tools [6] and also the identification of some aspect interactions.

Fig. 4 shows an example of a MATA rule defined in the sequence diagrams context. R1 specifies that the aspectual behavior consists of an interaction between 2 objects that must be instantiated to 2 objects in the base. The rule says that the fragment par (that specifies parallelism) and messages r and s in one of the sections of the fragment are created, i.e., they define the aspectual behavior that must be inserted in the base. However, since p is defined as "<<context>>", it must be matched against a message with the same name in the base. The resulting composed model when applying R1 is shown on the top right-hand corner of the figure. Note that since *q* and *b* are not part of the rule they come after the par fragment.

The starting point of the approach introduced in this paper is the identification and specification of crosscutting concerns, which is followed by their composition using the MATA language and sequence diagrams.

IV. Modeling Spatial Concerns with Aspects

Fig. 5 defines a process for modeling spatial concerns using aspects in Web-GIS applications. The process consists of three general activities: Identification, Specification and Composition. In the context of this paper, we will refine each of these activities to scenario modeling, where use cases and sequence diagrams are the techniques used.

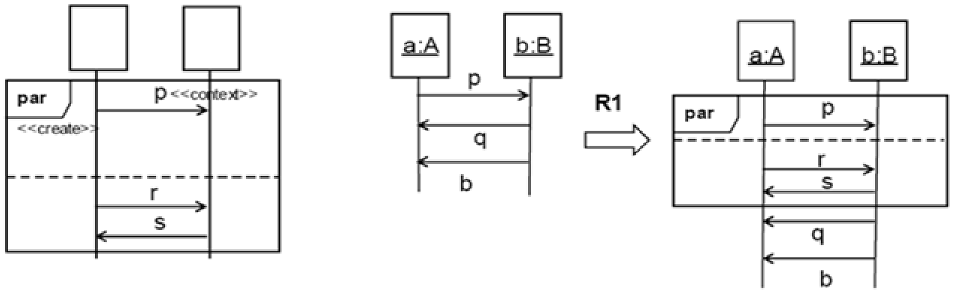

Fig. 4 An example for a MATA rule

The first activity, Identification of Use Cases and Crosscutting Relationships, identifies the use cases and represents the relations among crosscutting use cases using the stereotypes <<include>> and <<extend>>. That is, a use case that is included by several use cases or a use case that extends several ones is considered as crosscutting. In addition, we adopt the stereotype <<invokes>> [21] to be used when a use case activates one or more use cases.

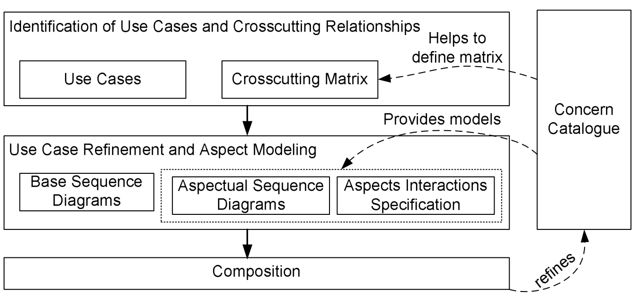

Fig. 5. Modeling GIS concerns with aspects

Although some works do not recommend describing dependencies between use cases, such as [13], we believe that pointing out use case relationships helps detecting crosscutting concerns, as it will be described next in the Use Case Refinement.

Our use case diagram is complemented with a crosscutting matrix that is used to detect possible crosscutting behavior between the use cases. Also, a "concern catalogue" can be used to contribute:

- to identify already recognized crosscutting concerns, but also contributions, or dependencies, between them and,
- to give feedback to logged concerns, enriching the concern information as well as its known-issues learned from experience.

The second activity, Use Case Refinement and Aspect Modeling, refines the use cases adding more detailed information and designs the crosscutting behavior between concerns taking into account the crosscutting matrix. The first task is to design the non-aspectual use cases (called base use cases) using UML sequence diagrams (that describe base scenarios). The second step comprises the modeling of aspectual use cases using UML sequence diagrams enhanced with MATA graph rules (i.e., aspectual scenarios). When a concern stored in the catalogue is recognized and selected for instantiation in the identification step, its consolidated models are reused profiting from full-fledged concerns.

From the relationships detected in the crosscutting matrix, we must identify the interaction and possible conflicts among aspects giving as result a consistent set of joinpoints. The aspects coexistence can lead to incorrect results when the aspects are composed. That is, an aspect may conflict with another; some of such information can also be taken from reusable catalogues. This occurs when an aspect changes models in such way that it prevents the application of another aspect. Jayaraman et al [12] propose an approach that can be used for detecting this situation where, by means of a Critical Pair Analysis [9] of MATA models, some aspect conflicts can be identified. If required, other aspect conflicts may be identified and solved using the AORA conflict resolution tool [4].

In the best cases, establishing an order in which aspects are applied respecting their dependencies is enough. In the worst cases, a rethinking of which aspects should be applied or remodelled is required [4, 14].

The last activity, Composition, composes the aspectual scenarios with the base scenarios using the MATA language. The composition activity shows that the crosscutting concerns can be isolated in aspects and then composed into one or more base scenarios, without changing the application execution. By isolating the crosscutting concerns, we promote modularization, reuse, and the evolution capabilities of the application. During composition, new interactions and conflicts can be identified. These should be used to refine and improve the information already contained in the catalogue.

So far we addressed a design where the base application concerns are oblivious with respect to candidate aspects and MATA properties have been introduced seamlessly in the approach.

Composition plays a primary role when a new requirement is required in the application. For example, in a GIS application, a street segment may be blocked while a maintenance task carries out excluding the compromised segment in path-finding algorithm execution. This kind of unforeseen concern is handled using the composition step to handling its activation and deactivation: Crosscutting relationships are specified using a crosscutting matrix. The solution is modeled using the MATA tool and composition is applied as required. Given that core concerns are oblivious with respect to the new unexpected GIS concern, this is easily introduced and removed from the application in the composition phase depending on the events that defines the volatile concern lifecycle.

In summary, let us stress a little more the creation of a catalog of GIS crosscutting concerns as a reuse mechanism. Once a crosscutting concern is localized, analyzed, and modeled it is introduced into the catalogue for later instantiation, storing, additionally to the models, usage information such as impact and results. Each time a concern is instantiated, it can suffer small refinements from user feedback, which will improve it.

V. CASE STUDY

Let us illustrate our approach using the GIS web application Maps@Web aiming at helping users in their daily activities. This web application provides a set of varied location-based services, including services related with Cinemas, Hotels, Universities or Police Stations. For instance, if the user wants to go to the university, to the cinema and to the supermarket, all in the same evening, this application will calculate an appropriate path to visit all these places.

To better demonstrate the contributions of our approach, let us add the new requirement "Indoor Representation". This requirement changes the user's application context, taking him to an indoor representation of space when the building fits the whole map view. Next we show how to apply the three activities in our approach.

A. *Identification of Use Cases and Crosscutting Relationships*

Fig. 6 shows a partial use case diagram, with the use case "Show Service" and the crosscutting concerns "Change Scale" and "Context Switch".

With the introduction of the "Indoor Representation" requirement, we now have two kinds of maps, Indoor Map and Outdoor Map. In this example, when the user starts using the application, an outdoor representation of the service location is shown, additionally exhibiting specific icons for points of interest. That is why the use case "Show Service" is connected with the concern "View Outdoor Map", with an <<include>> relationship. This last concern will be extended with "Change Scale" every time the map tool bar is changed. When the scale reaches the maximum zoom available, there will be a switch in the user's application context which enforces a swap between the outdoor and indoor views of the currently displayed location. We represent this relationship between "Change Scale" and "Context Switch" with an <<extend>> stereotype. When the scale reaches the maximum and the context changes, the "View Indoor Map" is invoked.

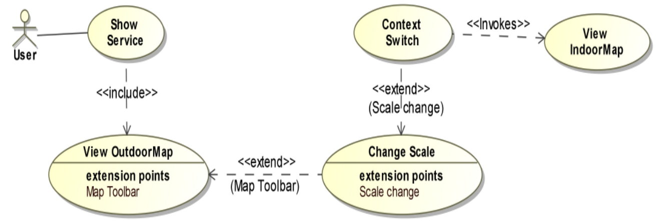

Fig. 6. Partial Use Case diagram for "Show Service". Use cases are enhanced with possible crosscutting concerns.

Table I illustrates the crosscutting behavior between the requirements in the GIS concerns and other application concerns, described by the corresponding use cases. As we can see, "Change Scale" and "Context Switch" are crosscutting concerns and they crosscut the same use cases; this may indicate that there is some interaction between them. This interaction will be solved later in this section.

TABLE I. RELATING CROSSCUTTING CONCERNS WITH USE CASES

CC Concerns / **Use Cases**	Change Scale	Context Switch
Manage Applications		
Create/Edit Main Service	X	X
Manage Service Net	X	X
Search by service/Address	X	X
Registration		
Edit Profile		
Edit Favourite Places	X	X
Edit Favourite Categories		
Show Suggestions	X	X

B. *Use Case Refinement and Aspect Modelling*

The second activity of the approach specifies the base scenarios (Fig. 7) and the crosscutting concerns with sequence diagrams (figures 8 and 9). Fig. 7 illustrates the use case "Show Suggestion" from our example.

Fig. 8 shows the crosscutting concern "Change Scale" represented with a MATA sequence diagram. The first message in this sequence diagram matches with the same one in the base scenario ("viewSuggestions(...)"), which is indicated by the <<context>> stereotype. Since changing scale is optional, it is represented with the "opt" fragment. Every message inside this fragment will be created in the base scenario, as is identified by the <<create>> stereotype.

Fig. 9 shows the crosscutting concern "Context Switch" that will be activated by the concern "Change Scale". The first message of the sequence diagram in Fig. 9 matches with the equivalent one in the base scenario. In this particular case, the base scenario is the aspect "Change Scale".

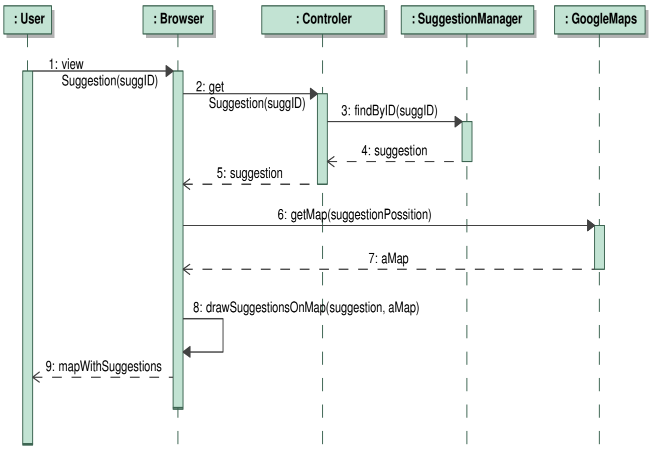

Fig. 7. Base Scenario "Show service".

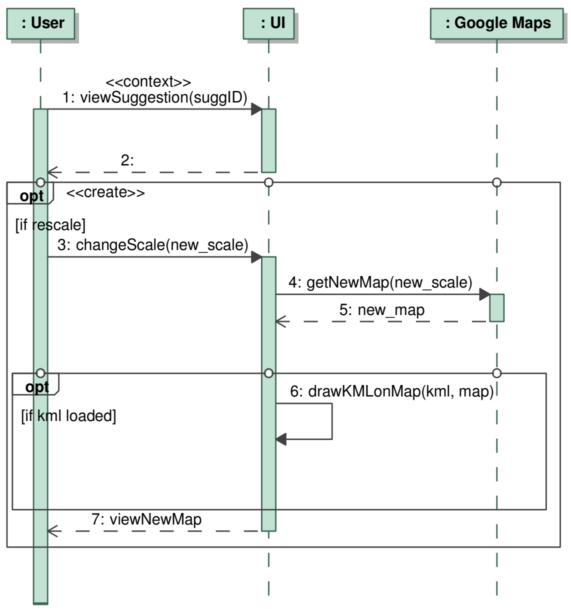

Fig. 8. Aspectual Scenario "Change Scale".

This sequence diagram shows that every time the user performs a change in the scale, the system will verify if a change in the spatial context is required. If this change is needed, the system accesses the information about the new context (in this case it is the indoor location). The "*any*" fragment allows the base scenario to continue its behavior, with a sequence of messages. At this point of the example, it is clear the interaction between "Change Scale" and "Context Switch". There are two indicating factors that point to this situation. First, in Table 1, these two aspects crosscut the same use cases. Second, the pattern matching of "Context Switch" will be made with another aspect, "Change Scale". The relationships between these two aspects are shown in Table 2.

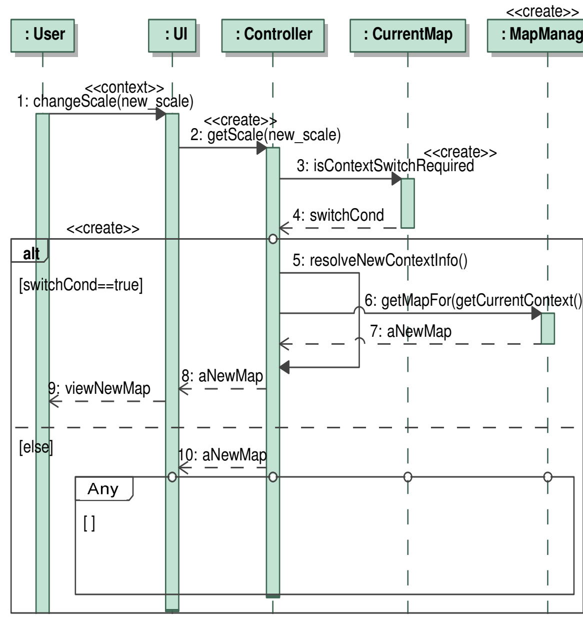

Fig. 9. Aspectual Scenario "Context Switch".

TABLE II. ASPECTS DEPENDENCIES

	Context Switch	Change Scale
Context Switch		Requires
Change Scale	Provokes	

As the relationships in Table 2 indicate, for a spatial context switch, a change in scale is required, which is triggered by the user. Moreover, the use of the maximum zoom level will lead to a change in the user's spatial context. As we can see in this particular example, the relationships between aspects are simple, which means that it is enough to establish an order, taking into account their dependencies, in which aspects can be composed: "Change Scale before Context Switch".

C. Composition

This activity composes the aspectual scenarios with the base scenarios. Fig. 10 depicts the base scenario "Show Suggestion" depicted in Fig. 7, composed with the aspectual scenarios "Change Scale" depicted in Fig. 8, and "Context Switch" depicted in Fig. 9. This composition is accomplished while respecting the MATA rules, defined as patterns in the aspectual scenarios and then, doing the pattern matching with the base scenario. As it can be seen in Fig. 7, the first message ("viewSuggestion") matches the first message of the diagram in Fig. 8. This matching represents a joinpoint where the aspectual scenario, in this case "Change Scale", will be inserted in the base scenario. The next pattern matching will accomplished between the second message in Fig. 8 and the first message in Fig. 9. This means that the behaviour from aspectual scenario "Context Switch" is added to the composed scenario. The fragment "any" at the bottom of the aspectual scenario "Context Switch" will be matched with the rest of the aspectual scenario "Change Scale". Therefore, the matched fragment will be inserted in the composed scenario.

VI. BUILDING A KNOWLEDGE BASE

So far we have analyzed and designed GIS crosscutting concerns promoting solutions which are characterized mainly by a weak coupling between resulting components, allowing a high level of reuse. Indeed, solutions must be both seamless, avoiding coupling between components and easing composition, and oblivious to the core concerns, removing any impact of new concerns introduction given that concerns are not aware to each other.

This was the drive to propose a reuse mechanism based on a catalogue of GIS concerns, defined in a very abstract and system-independent fashion. This catalogue should be used to help eliciting the problem domain concerns. The idea is to use these documented concerns when organizing the system space requirements (where the application domain is described), so that concerns of the problem domain are identified.

The catalogue is fed with concerns as they are analyzed and designed by system architects. Nonetheless, these concerns are not static and can evolve as long as they are instantiated and reused in other applications being improved, and if required modified, with usage feedback. Documented concerns are described with MATA models, which are used when this is recognized in the system space. These models are supposed to be refined as they are applied in different systems.

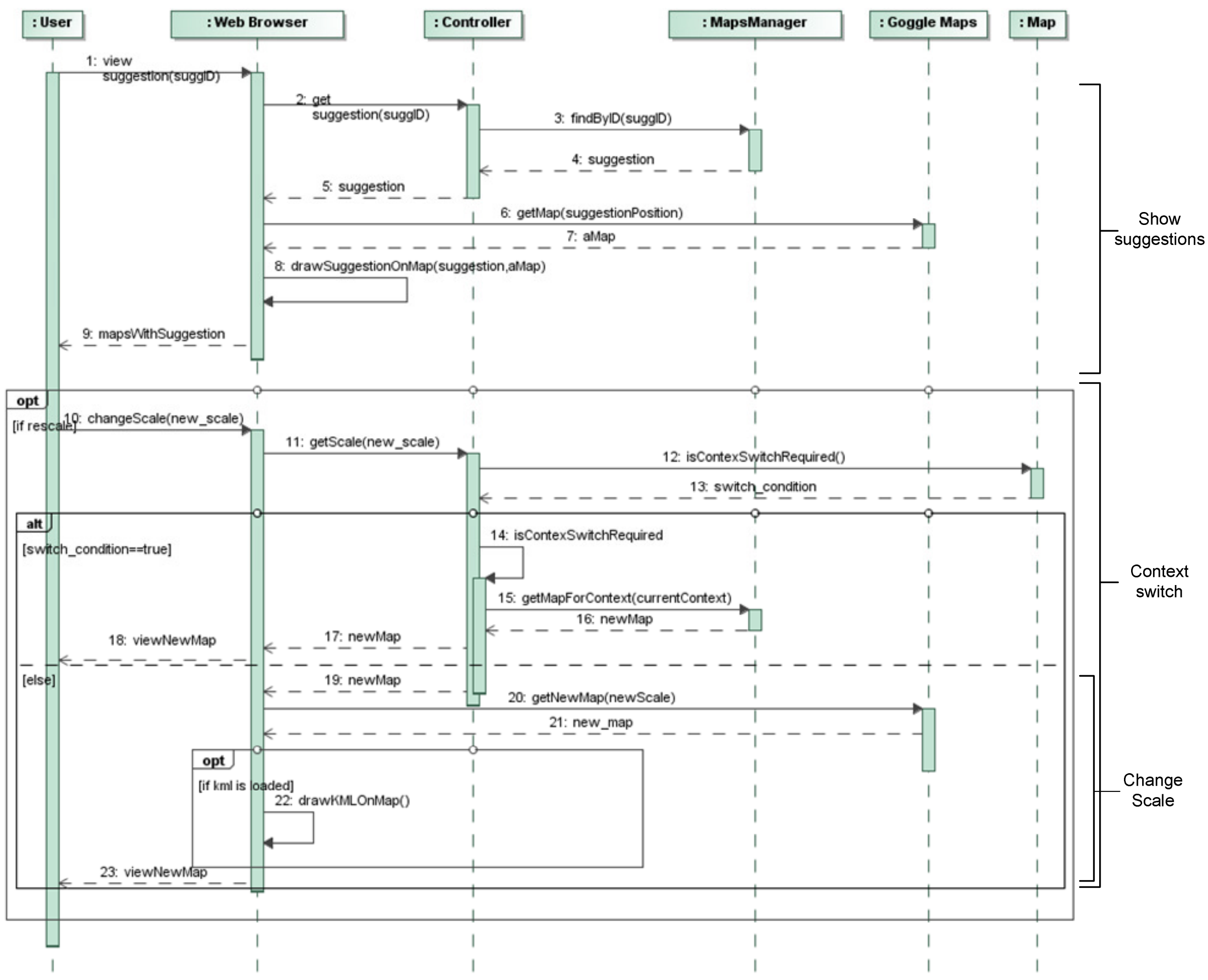

Fig. 10: Composed Scenario

Each GIS concern can be documented using a simple template composed of the following five fields:

1. **Name**: a short name describing the concern
2. **Description**: a brief description of the concern;
3. **Requirements**: concern's requirements must be clearly described for an appropriated understanding of current concern;
4. **Solutions**: an explanation of how to solve the problem using the described aspect-oriented approach. Here the solution is documented using UML use cases and sequence diagrams combined with the MATA tool as it was explained in section 4 and exemplified in section 5.
5. **Experience**: a brief description about the instantiation context in which this concern has been introduced. At least the application which initially required the GIS concern.

Furthermore, *known issues* and *consequences* items can aggregate value to the catalogue. The former will describe those exceptions and limitations in the appliance of the concern, while the latter will describe the impact in the target application.

A. *Example*

To illustrate the use of the catalogue, we next describe a concern, comprising a set of requirements, which enables the attachment of descriptive information to a location aware business object, such as a "Point Of Sales" or a "Hotel". A catalogue entry for this concern will look as the following:

- **Name**: Comment support
- **Description**: a business object with spatial capabilities must be enriched with user comments information (the name of a place for example). It is commonly required to add new information to this data (e.g., to add a place description in a map).
- **Requirements**: Requirements for this concern are:
  - Users can add comments to spatial object for sharing knowledge.
  - Users need map editing facilities for adding comments.
  - Comments must be presented in a suitable fashion over the map.
- **Solution:** The solution for this concern covers two models: class diagram, and sequence diagram. Fig.11 shows a class diagram which introduces a relationship named "comments" that has, as source, any spatial object (object which is aware of its position) and, as target, a "Comment" class, holding a simple text variable. After applying the MATA composition process (described in section III.A) to the base business model with the MATA specification for the Comment concern, spatial business objects will contain a variable for a collection of Comments.

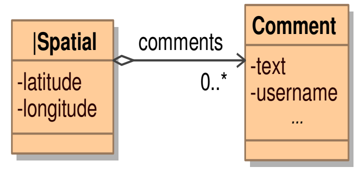

Fig. 11: MATA models for adding comments to business objects

  To satisfy the user interface requirements, Fig. 12 presents a sequence a diagram that decorates the visualization of Maps with the logic for rendering Comments. That is, the diagram introduces a lookup sequence for determining registered comment for business elements placed into the current map's view, and a rendering sequence for drawing resolved comments.
- **Experience:** This simple, but useful, aspect has been introduced successfully in applications, such as Google maps. The result was an improved user experience of the application, which follows a knowledge sharing alignment of Web 2.0 applications. Fig. 13 shows the usage of the Comment concern.

VII. DISCUSSION

The identification of crosscutting concerns in early stages of the software development process has proved to be effective for improving modularization and thus increasing the localization software engineering principle, which facilitates maintenance of software applications. For example, we were able to modularize the concerns Context Switch, Change Scale, Comment support, which, otherwise, would be scattered in an object-oriented model, for example. Using the approach, these concerns were designed in an isolated fashion avoiding core concern being aware of them, simplifying the concern maintenance and reducing the system complexity.

In the context of Web-GIS applications, by identifying and characterizing spatial concerns early, according to their crosscutting nature (e.g. introducing scattered and tangled code into application´s core concerns), we not only help improve spatial components' modularity but also improve their reuse. The catalogue of GIS concern is the knowledge base where concern's information is stored. As it was shown in the example of section VI, the "Comment support" concern can be instantiated in any application where, at least one of its business objects matches proposed MATA rule. That is any application that has business objects with spatial information (latitude and longitude).

In this environment, the use of a tool like MATA simplifies the process of understanding how composition of separated concerns will work, and helps guaranteeing their correctness as well as some unwanted interactions.

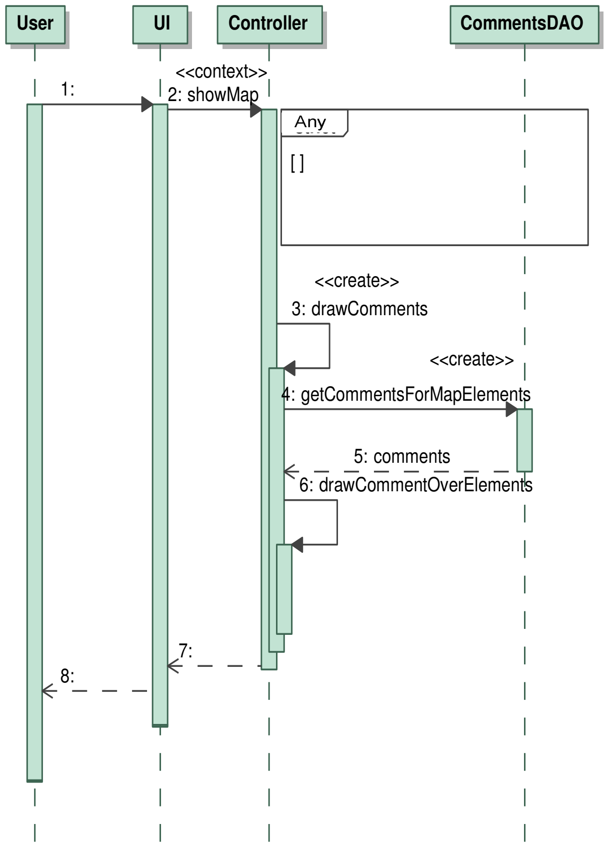

Fig. 12: Sequence diagram for presenting comments

Fig. 13: Comment concern example

The case study demonstrated how we were able to modularize the requirements "Change Scale" and "Context Switch" using aspects, which, otherwise, would be scattered along several other modules. By using the MATA tool, concern connections are expressed in terms of pattern matching expressions avoiding the replication of modeled behavior across the application. That is, everyplace a pattern is satisfied, the MATA model is instantiated.

VIII. Related Work

The use of advanced separation of concerns techniques and particularly the use of aspects have been recently proposed for the development of complex Web applications, mainly to provide adaptation behaviours [2]. However, to our knowledge, there has been no research on the modularization of spatial concerns in Web-GIS software.

In the more general field of context-aware software, Munnelly [17] presents an approach for modularizing context-aware systems by encapsulating different types of context (e.g., location, user and device context) using an aspect-oriented approach. Our paper demonstrates that a context-aware application built in this way exhibits improved modularity, with corresponding improvements in comprehensibility, manageability and maintainability. Because it lacks of a process that gives support to the detection and design of adaptation concerns, this approach can be complemented with ours introducing the presented process for modelling spatial concerns in the early stages of software engineering.

Carton [5] presents an approach to manage the development of applications for pervasive computing, based on a combination of aspect-oriented development techniques with model-driven development. This approach suggests modelling the pervasive application in Theme/UML and using model-driven transformations to gain the additional benefits of platform and technology independence. Besides the fact that this approach takes the advantage of model-driven development, our approach uses MATA to specify and compose aspects, and the process we presented is more elaborated than the one presented in Carton [5].

Zipf and Merdes [26] discuss the use of aspects in GIS applications. However they only focus on the programming level while we focus on the earlier stages of software development. However, their analysis of possible spatial concerns is similar to ours.

Our approach can be enhanced with HILA (High-Level Aspect) [25] when an aspect introduces changes on components' state. HiLA presents an UML extension for modelling crosscutting behaviour in state machines that enables the graphical description of aspects' elements (like pointcuts and advices).

IX. Conclusions and Future Work

Our approach modularizes spatial concerns (e.g., location-awareness and scale change), in Web-GIS applications. The process is composed of three main activities: identification, specification and composition. In this last activity MATA is used to compose aspectual models with base models.

We have shown that the quality of volatile applications like Web-GIS, always in constant change, can be improved by enhancing the respective modularity of spatial concerns. Our view represents a step forward with respect to existing approaches in which the spatial concerns are mixed with other crosscutting application concerns.

Currently we are working on the identification and modelling of additional spatial concerns with the aim of developing a catalogue which will let us elaborate new applications through composition, following the methodology presented in this paper.

ACKNOWLEDGMENTS

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