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Driving and Managing Architectural Decisions with Aspects*

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Abstract: Software architects face decisions every day which have a broadly-scoped impact on the software architecture. These decisions are the core of the architecting process as they typically have implications in a multitude of architectural elements and views. Without an explicit representation and management of those crucial choices, architects can not properly communicate and reason about them and their crosscutting effects. The result is a number of architectural breakdowns, such as decreased evolvability, time-consuming trade-off analysis, and unmanageable traceability. Aspects are a natural way to capture widely-scoped architectural decisions and promote software architectures with superior modularity.

Keywords: architectural decisions, modularity, composability, aspects.

Resumo: Arquitetos de software se deparam diariamente com decisões que têm um amplo impacto na arquitetura de software. Essas decisões são essenciais para o processo de definição da arquitetura, pois tipicamente têm implicações em muitos elementos e visões arquiteturais. Sem uma representação explícita e gerenciamento dessas decisões, os arquitetos não são capazes de comunicar e raciocinar sobre elas e seus efeitos que entrecortam várias partes da arquitetura. Isso resulta em problemas arquiteturais, tais como diminuição da facilidade de evolução, análise de custo-benefício difícil de ser feita e dificuldade de gerenciamento da rastreabilidade. Aspectos são um caminho natural para capturar decisões arquiteturais de amplo escopo e promover arquiteturas de software com modularidade superior.

Palavras-chave: decisões arquiteturais, modularidade, facilidade de composição, aspectos.

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1 Motivation

Software architecture is a fundamental element of modern software systems. Architects strive to develop adaptable architectures that are resilient in the face of changes especially for systems in volatile business domains such as eCommerce, banking, and telecommunications. In order to be adaptable, architectures must be modular. This serves a twofold purpose. If architectures are modular one can reason about individual architectural elements in isolation. This is termed modular reasoning [1]. At the same time, the various modules need to relate to each other in a systematic and coherent fashion to realize the intended architecture. Effective representation and specification of such relationships makes it possible to reason about the architecture as a whole – using the modular reasoning outcomes as a basis. We refer to this global reasoning as compositional reasoning.

Existing software architecture design and analysis approaches are geared towards supporting such modular and compositional reasoning. Architectural styles and patterns [9], for instance, are based on the recognition of the effectiveness of specific organizational principles and structures. This helps one to undertake compositional reasoning about the elements deployed using a particular architectural pattern or style. Similarly, the notion of architectural components and connectors supports modular reasoning about individual architectural elements, i.e. the components, as well as compositional reasoning based on their relationships captured by the connectors. The Architecture Trade-off Analysis Method (ATAM) [3] supports modular reasoning by building and maintaining both quantitative and qualitative models of various competing quality attributes. These models are then composed to carry out compositional reasoning for identifying trade-off points. The "4+1" view model [5] separates an architecture into logical, process, physical, and development views, derived from the various stakeholders' perspectives. This makes it possible for an architect to modularly reason about each of the views. A fifth view, the scenario or use case view, shows how elements in the other views work together thus supporting compositional reasoning.

Architectural decisions play a fundamental role in support of such modular and compositional reasoning as they are the driving force behind the architecture conception. They encompass critical architectural choices which have both structural and behavioral implications for the various architectural elements and the architecture we wish to reason about. It is, therefore, important to document architectural decisions in a systematic fashion. Tyree and Akerman [6] motivate the need for such documentation to support conveying of change, implications, rationale and options as well as facilitate traceability and provide agile documentation. Our experience, however, shows that documenting architectural decisions alone is not sufficient. Architectural decisions have a broadly-scoped impact on the architecture.

Take, for instance, the "4+1" view of a software architecture that addresses several broadly-scoped properties, such as availability. When attempting to understand the availability-specific architectural decisions and their implications, an architect needs to reason across the various views, i.e. the logical, process, physical, and development views. This is because those availability decisions are likely to relate to multiple elements across more those views. This is particularly challenging as architectural decisions often lead to addition of new structure or behavior within a view. Since these implications are scattered across various view elements and views themselves, it is

difficult to undertake modular reasoning about a particular decision. Compositional reasoning is even more challenging as one needs to understand the combined implications of various architectural decisions spanning a multitude of elements across several views.

This implies that, in addition to systematic documentation of a decision, it is important to capture the additional behavior and structure it introduces into the various elements in the views. Furthermore, it is important to provide a composition mechanism that can quantify over the various elements in the views to compose such additional behavior and structure. This would support an architect to undertake modular reasoning about a decision and its implications. More importantly, by systematically exposing the semantics of a decision's compositional relationship with architectural elements, we can support an architect to undertake compositional reasoning about the combined implications and trade-offs of various architectural decisions.

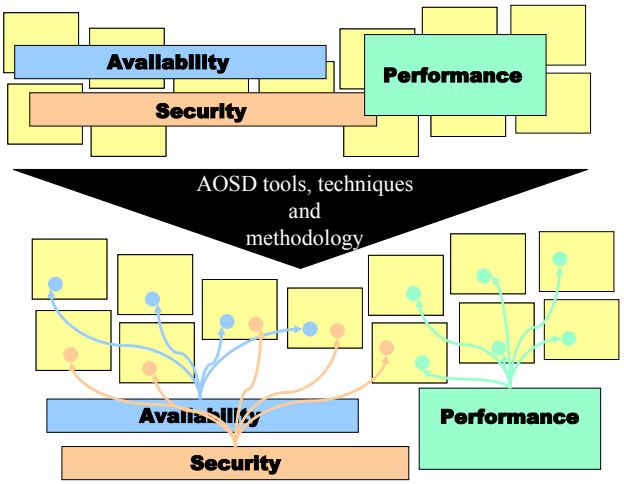
Our approach to providing such modular and compositional reasoning support is based on the use of aspect-oriented software development (AOSD) techniques [8, 10]. AOSD techniques provide additional support for modular and compositional reasoning by separating concerns that would otherwise be interspersed with other concerns in a software system. We can see from Figure 1a that AOSD techniques make it possible to modularize such concerns hence supporting modular reasoning about them. At the same time, they provide a composition mechanism centered on the notion of join points, which are effectively a composition interface exposed on part of the non-aspectual elements of a system to facilitate aspect composition. Hence, the notion of a join point model and the composition specification based on it facilitates compositional reasoning about broadly-scoped properties in a system. Since decisions have a broadly-scoped impact on the architecture they lend themselves as natural candidates to be aspectized.

2 Aspects Driving Architectural Decisions

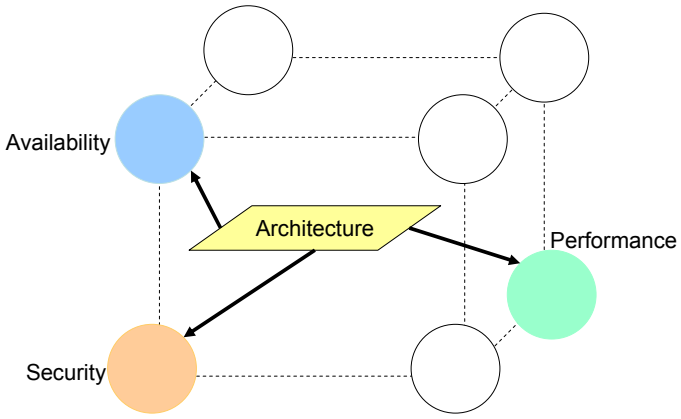
Software is no longer engineered using a rigid separation of development stages. With the increasing adoption of iterative and agile methodologies, gone are the times when a strict separation between requirements engineering, architecture, design, implementation, and evolution was perceived as good practice. Key architectural decisions may be taken as early as requirements engineering. This is particularly true for COTS-based systems development where early risk analysis is important to understand the implications of using components with different communication mechanisms, data formats, etc.

Broadly-scoped concerns, whether functional or non-functional, e.g., availability, security, performance, informational retrieval, etc., identified during requirements engineering have important architectural implications. Aspect-oriented requirements engineering techniques [7] make it possible to systematically identify, modularize, represent, and compose such broadly-scoped concerns. Such techniques, therefore, make it possible to modularly reason about such concerns as well as undertake compositional analysis for early identification of trade-offs among them. These broadly-scoped concerns and their mutual trade-offs provide early insights into the various architectural decisions facing an architect. As shown in Figure 1b, these concerns can be perceived to be various nodes of a lattice. Each concern leads to a set of architectural decisions. The mutual trade-offs exerted by the concerns, and the

decisions driven by them, pull the architecture in various directions. The decisions need to be elaborated and represented in a modular fashion during architecture design. Effective modular and compositional reasoning about such architectural decisions is what helps the architect find the optimum point within the lattice where the final system architecture, satisfying the stakeholders' concerns, would reside.



(a) Modular and compositional reasoning about broadly-scoped properties using AOSD. The colored dots represent join points used by the various aspects that have been modularized. The colored arrows are the composition specification using these join points.



(b) Architectural *pull* exerted by decisions pertaining to aspects. For simplification, we have only highlighted three lattice nodes. Note that the lattice can have as many number of nodes as the aspects found in the requirements specification.

Figure 1. AOSD and Architectural Decisions

3 Crosscutting Architectural Decisions

Although the explicit handling and representation of architectural decisions are of paramount importance, they are not trivial tasks. Many decisions associated with relevant architectural concerns are crosscutting by their very nature and, as result, they need to be treated as such. They cut through the primary modularities of the architecture description, which is often consisted of one or more views. An architectural concern can affect several elements in an architecture description, such as

components and their interfaces, relationships, processes, and also the decisions associated with other concerns.

In order to understand these problems, consider the architecture of a context-sensitive tour guide system. Figure 2 shows a partial description of the software architecture for this example based on a component-and-connector view [2] and on additional views from the "4+1" view model [5]. The upper left depicts a structural diagram with the component-and-connector view. The visitors use a Navigator to navigate through a tour, to create a customized tour, and to update information about the navigation preferences. The Navigator component contacts the InformationRetrieval component to recover information from the system. The Navigator also contacts the ExternalServices component to connect the visitor to external services. The LocationManager provides the identification of the current location of a visitor. This identification is used by the InformationRetrieval component that provides tourist information according to his/her current location. The TouristInfoManager allows the tourist centre to update information in the system.

In this structural perspective of the tour guide architecture, it is also clear that the decisions with respect to the availability requirement affect several points of the architecture specification. Although availability-specific choices are somewhat localized in the ReplicationManager component, they largely impact on the definition of several interfaces and components, which do not have the primary purpose of addressing availability issues. Availability-related decisions crosscut multiple components, including InformationRetrieval, LocationManager, and TouristInfoManager. As availability support requires the replication of critical components and the consistency management of their replicas, specific components and interfaces need to be created and added to those affected components. The crosscutting phenomenon also involves other concerns, such as security and performance.

The crosscutting manifestation leads to two major problems at the architectural level, the so-called *scattering* and *tangling*. Architectural scattering is the manifestation of architectural decisions, which belong to one specific concern, in several architectural units encapsulating architectural decisions referred to other architectural concerns. For example, the replication-related interfaces are scattered over multiple architectural components, such as LocationManager, InformationRetrieval, TouristInfoManager components (upper left of Figure 2). Architectural tangling is the mix of multiple concerns together in the same architectural elements. For instance, tangling is evident in the InformationRetrieval component since it is realizing an availability-related interface in addition to its primary functionality of providing information.

As previously mentioned, there are some architectural aspects which bring deeper problems to the software architects; they can even crosscut other architectural views in addition to the structural view, as it is the case for the availability concern. The availability-specific decisions are scattered and tangled within elements of other concerns over the four architectural views. Availability requires not only the inclusion of components, interfaces, and connectors (component-and-connector view), but also the definition of two separate threads to manage both replication and consistency (process view), the conception of the management layer together with other supplementary managers (development view), and the distribution of replication elements through different servers (physical view).

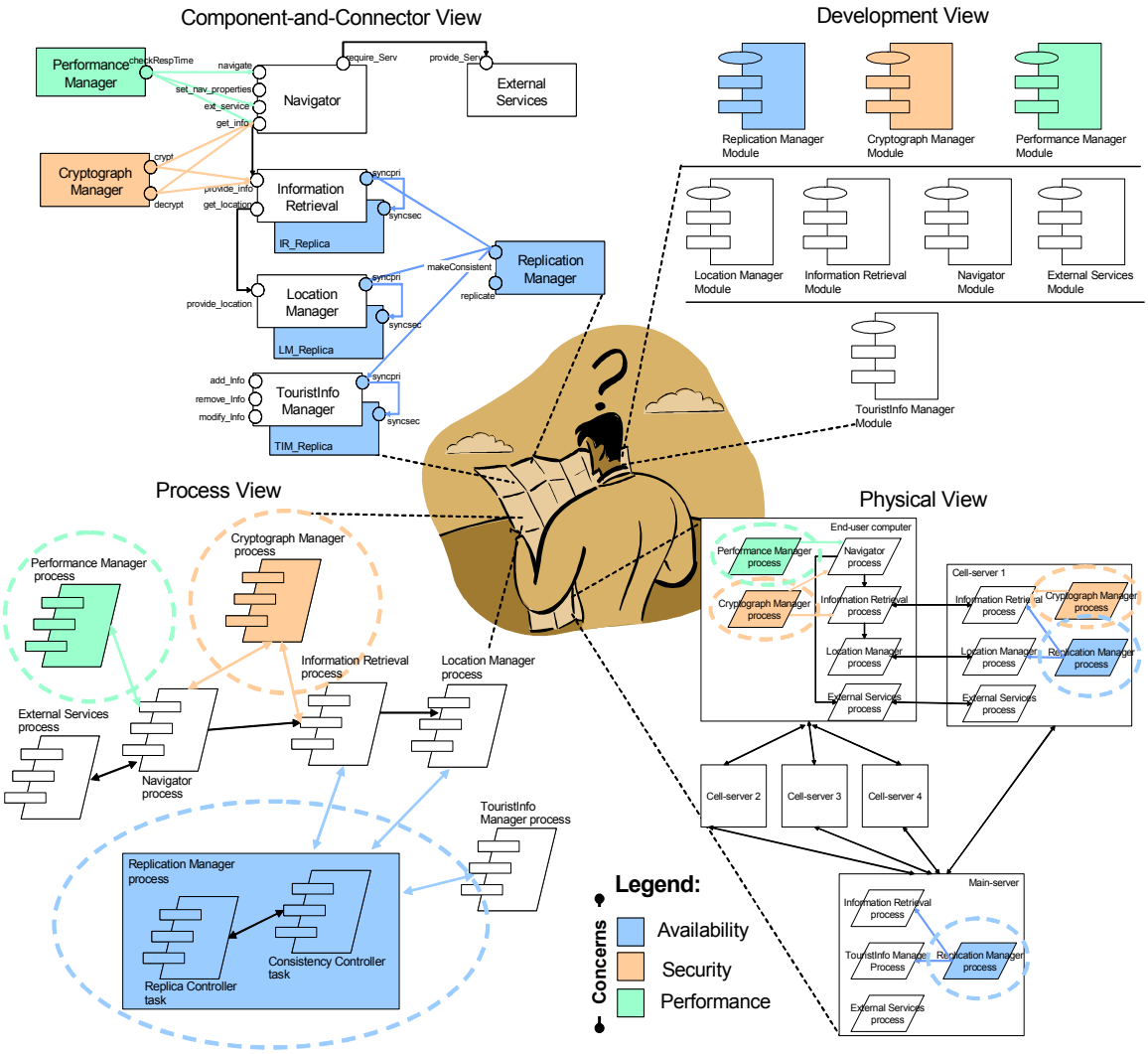


Figure 2. Tangling and Scattering in an Architecture Description

Traditional architectural approaches such as 4+1 view model [5], ATAM [3], tatics [2], and architectural styles or patterns [9] have different complementary purposes. However, they are not aimed at supporting the separate handling of crosscutting architectural decisions as exemplified in Figure 2. It brings in turn a number of substantial pitfalls, such as:

- *Hindering of modular and compositional reasoning.* Tangling and scattering of decisions hinder both modular and compositional reasoning at the architectural stage. The architects are unable to reason about an architectural concern while looking only at its description, including its core decisions and structural and behavioral implications. Hence its analysis inevitably forces architects to consider all the architectural artifacts in an *ad hoc* manner. For example, the architects treating the availability and security concerns in Figure 2 need to consult the definitions and decisions associated with all other architectural concerns across all the different views.

- *Traceability is unmanageable.* Many of the concerns in the requirements specification entail crosscutting architectural decisions. The mapping of those concerns to the

respective decisions is awkward as the developers do not have proper ways to easily check whether and how the requirements are met in the software architecture. For example, the association of availability-specific requirements with their architectural implications is cumbersome and far from being trivial. This obstacle makes it difficult to assess the goodness of the software architecture even in the presence of a good requirements engineering process.

- *Decreasing evolvability.* Architecture degeneration is becoming very common in an age where software systems are always changing. Architecture artifacts are often key deliverables in the evolution process. As a consequence, the architects have additional work to answer recurring questions: What happens if we decide to change security-related components of our system? Has this decision been affected by which architectural concerns? As a complex architecture probably reflects thousands of crosscutting decisions, finding the answers for these questions is naturally time-consuming, especially when the original architects are no longer available.

- *Loosing essential information.* With traditional approaches, software architects are not able to locally express the structural and behavioral implications of a given architectural decision in several architectural elements and views. The result is that important information is irrecoverable just because the lack of support for properly specifying them. Not only the final choices can be lost, but also the crosscutting rationale and competing options the architects considered.

- *Reducing reuse possibilities.* Tangling and scattering are two of the main anti-reuse factors in the software lifecycle. The lack of a clear separation of concerns generates undesirable burdens on architectural reuse. For example, software architects may want to recycle, or at least remember, a comprehensive list of decisions and the rationale associated with an architectural concern in posterior projects. It would be certainly beneficial in order to empower software architects to reuse successful crosscutting architectural choices from previous projects.

4 Capturing Architectural Decisions as Aspects

In the light of the mentioned problems, we conjecture that crosscutting architectural decisions should be handled as separate architectural aspects. The idea is to have proper abstractions to enable their representation as first-class elements, and also provide the means to facilitate their further composition. Aspects were originally conceived to address crosscutting concerns at the programming level [10]. It is then natural to believe that the key for capturing crosscutting architectural decisions is exploiting some AOSD concepts [8] at the architectural level.

Architectural aspects are units of modularity to capture the decisions associated with broadly-scoped concerns, letting the architects to represent all the structural and behavioral implications in a single place. Figure 3 shows templates to specify architectural aspects with essential information to capture crosscutting decisions:

- name of the architectural aspect;
- structural and behavioral architectural decisions, such as the inclusion of components, interfaces, relationships, processes, and so forth, which were made with the sole purpose of contemplating issues related to the architectural aspect;

- composition rules to describe how the crosscutting decisions with respect to this architectural aspect affects other architectural elements and alternatively other aspects;
- a reasoning section that captures the rationale behind those decisions.

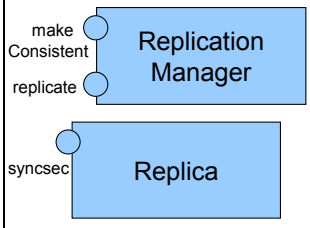
The crosscutting decisions affect several architecture elements, which are named *architectural joint points*. An architectural join point is an element of interest in the software architecture description through which two or more architectural decisions may be composed. Examples of join points are: a component, an interface, a process, an architectural aspect, or even an architectural decision. *Architectural composition rules* support the composition specification and enable compositional reasoning. They are means of referring to collections of architectural join points and describing some architectural decisions to be applied at those join points.

Figure 3 shows how to use the notion of architectural aspects to support the modular description of the availability, security and performance concerns in our running example. All the availability-specific decisions are clearly captured in the first template, including the creation of a ReplicationManager and system replicas, and the definition of two processes for controlling the system replicas and their global consistency. The rationale behind the availability decisions are reported in the reasoning section of the template. The reasons are related to structural and behavioral decisions as well as the composition decisions. In a similar way, the security-related and performance-related decisions are respectively isolated in the second and third templates.

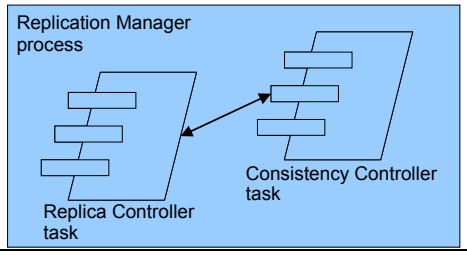
As a result, the template-based specification is a cohesive manner to describe those broadly-influencing concerns which otherwise would be scattered and tangled over the architecture description and its multiple views. Notice that this approach is general and agnostic to different architectural representations that the software developers are relying on, whether graphical or textual, such as ADLs (Architectural Description Languages), UML-based or XML-based notations. The software architect can also use the templates in conjunction with multiple architectural views, and any existing notations for reflective design, where design rationale is extensively recorded [6]. In fact, the template can be used to describe all the kinds of architectural decisions and rationale, including assumptions, constraints, positions, arguments, status, and the like.

Aspect: Availability

Structural Decisions



Behavioral Decisions



Composition Rules

componentSet = InformationRetrieval, LocationManager, TouristInfoManager.

replicaQuantity = 1

replicaSet = replicate(componentSet, replicaQuantity)

makeConsistent(replicaSet, componentSet)

Reasoning

ReplicationManager is in charge of replicating the critical components through the *replicate* interface in order to increase the availability of their provided services. N-Version programming is the software replication technique chosen due its implementation simplicity. Consistency is achieved through the interface *makeConsistent*, which synchronizes the replica results with the primary component results; thus the unification of the results also allows for other client components viewing the pairs of primary and backup elements as a single component.

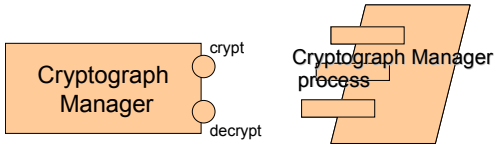
Each *Replica* component must provide a *syncsec* interface to collaborate with the primary component before the result of the component services are delivered to the client.

The *ReplicationManager* process is decomposed into two processes, *ReplicaController* and *Consistency Controller*, in order to decouple these two tasks.

Aspect: Security

Structural Decisions

Behavioral Decisions



Composition Rules

crypt(Navigator.get_info, before)

decrypt(Navigator.get_info, after)

decrypt(InformationRetrieval.provide_info, before)

crypt(InformationRetrieval.provide_info, after)

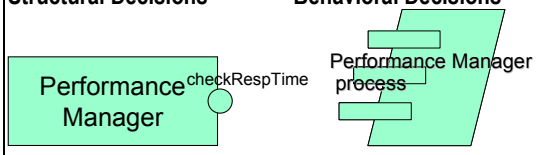
Reasoning

CryptographManager is responsible for encrypting and decrypting information using the *crypt* and *decrypt* interfaces. It affects the *get_info* service of the *Navigator* component. The parameters of *get_info* are encrypted. The encrypted solicitation is sent to the *InformationRetrieval*. This component decrypts the data to identify the solicitation, processes it, and encrypts the desired information before sending them back to the *get_info* service. Then, the final step is to decrypt the returned information.

Aspect: Performance

Structural Decisions

Behavioral Decisions



Composition Rules

monitoredServices = navigate, ext_service, get_info.

checkRespTime(monitoredServices, during)

constrain(Availability.replicaQuantity <=2)

Reasoning

PerformanceManager is responsible for encapsulating a timer and monitoring through *checkRespTime* the response time of critical services of *Navigator*. Performance also imposes an important upper bound in the number of replicas (*replicaQuantity*) defined in the *Availability* aspect.

Figure 3. Modularizing and Composing Architectural Aspects

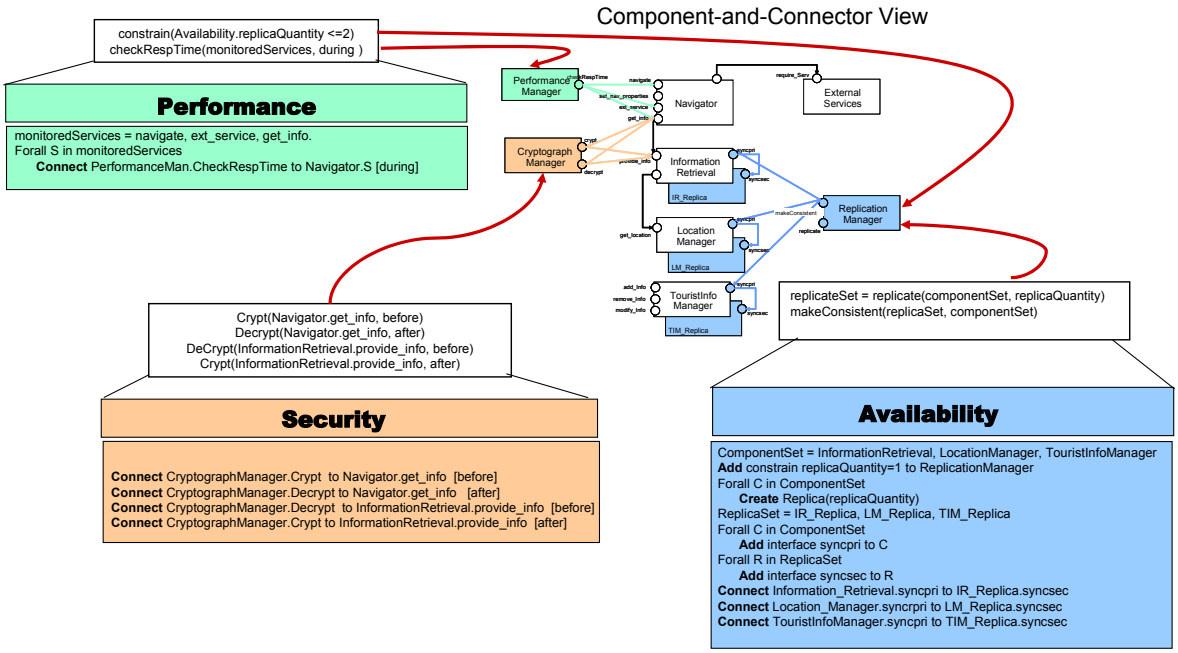
5 Composing Architectural Decisions

Properly documenting the composition of architecture decisions is critical because architects make them in complex environments and they involve trade-offs. The architects can use a high-level composition language to facilitate the registration and communication of broadly-scoped choices and enhance compositional reasoning. Figure 3 shows how to work with a high-level language to describe those choices as architectural composition rules. The naming of the architectural decisions is intuitive as it actually captures the architectural operation associated with the crosscutting decisions.

For example, the third composition rule in the first template (Figure 3), named replicate, captures the fact that a list of architectural components should be replicated due to availability purposes. Auxiliary declarations can be made in order to facilitate the quantification process, such as the use of componentSet and replicaSet. The first rule uses componentSet to quantify the architectural join points affected by the replicate decision. Those points are critical components to be duplicated with different implementation versions, namely InformationRetrieval, LocationManager, and TouristInfoManager. The rule makeConsistent abstracts the process of including architectural elements to address the consistency of the primary components and their replicas.

To facilitate the composition of architectural decisions, the rules can pick out different types of architectural join points, such as interfaces or even rules defined in other architectural aspects. Figure 3 shows the crypt and decrypt decisions in the security aspect affect interfaces of Navigator and InformationRetrieval. The third rule of the performance aspect, named constrain, influences an availability rule that specifies the number of replicas. This rule represents a recurring scenario faced by software architects: several aspectual decisions affect each other. The aspect-oriented templates promote composition interfaces that allow for the architect to make it explicit the relationships and mutual influences of broadly-scoped concerns, which are not easily captured in traditional architectural views. In fact, this architectural constraint involving performance and availability components was not explicitly represented by any of the views in Figure 2. Some behavioral information can also be part of the composition rules. For instance, the specification of the security aspect also includes "when" the crypt and decrypt decisions should actuate over specific architectural elements, i.e. "before" and "after" requests of services of Navigator and InformationRetrieval.

As previously mentioned, architectural aspects can influence decisions made in several views. The architect may want now to review together the crosscutting decisions and the architectural views with the rest of the project team and the project stakeholders. Hence once the architectural aspects have been defined, the actual effect of the decisions in the multiple views may need to be specified and analyzed. The next alternative step then would be to use underlying composition mechanisms to support the mapping of aspectual decisions in terms of elements of the other architectural views. Those mechanisms can rely on mapping rules that simply translate the aspectual decisions in terms of the corresponding elements in the architectural views. Figure 4a shows how those mapping rules could be applied for mapping availability, security, and performance decisions to elements of a component-and-connector view. A similar mapping process could be carried out for the other architectural views. Figure 4b shows a table with a foundational set of mapping rules.



(a) The Effects of Architectural Aspects in the Component-and-Connector View

MAPPING RULE	DESCRIPTION
Add <*elem_type* > <*elem_name1 [=value]*> ***to*** <*elem_name2*>	introduces an architectural element of type <elem_type> and name <elem_name1>, optionally set its value, to other architectural element <elem_name2>
Modify <*elem_name1*> ***to*** <*elem_name2 | value*>	changes the semantics of an architectural element by modifying its name from <elem_name1> to <elem_name2> or setting a new value to <elem_name1>
Remove <*elem_type*> <*elem_name1*> ***from*** < *elem_namet2*>	removes an architectural element of type <elem_type> and name <elem_name1> from other architectural element <elem_name2>
Split <*elem_type* > <*elem_name*> ***into*** <*elem_name_list*>	separates an architectural element of type <elem_type> and name <elem_name> into two or more elements defined in <elem_name_list>
Unify <*elem_type* ><*elem_name_list*> ***into*** <*elem_name*>	groups two or more architectural elements defined in <elem_name_list> in the architectural element <elem_name>
Connect <*elem_name1*> ***to*** <*elem_name2*>	defines a relationship between the elements <elem_name1> and <elem_name2>
Disconnect <*elem_name1*> ***from*** <*elem_name2*>	removes a relationship between the elements <elem_name1> and <elem_name2>

(b) Mapping Rules

Figure 4. Mapping Architectural Aspects to Architectural Views

6 What are the Benefits?

In the beginning, we identified numerous problems in conventional architecture-centric development approaches. By aspectizing crosscutting architectural decisions, we were able to address those issues and bring additional benefits:

- *Promoting modular and compositional reasoning of architectural decisions.* With aspectual templates architects can reason about the otherwise crosscutting concerns in isolated and combined manners. In fact, the template sections describing the reasoning and the composition rules are more than just simple decisions – they also communicate the compositional rationale, and from were the structural and behavioral decisions came from.

- *Ease of traceability***.** Architectural aspectization lets you trace decisions back to concerns in requirements (such as, availability, performance, and security). It also improves the identification of candidates to design and implementation aspects, linking them with their counterparts in the design and implementation artifacts. Moreover the composition rules inform the design team that those architectural elements are potential structures and behaviors to be modularized as design and implementation aspects.

- *Enhancing evolvability*. In architectural evolution processes, the aspectual templates let architects by and large know the effects the previous design decisions had in the evolving system. Without such an explicit handling of architectural choices, the evolution process would likely lead to the violation of relevant crosscutting assumptions and influences that were not properly documented just because there was no proper support for their expression.

- *Promoting knowledge management and reuse.* An aspect-oriented approach enriches the knowledge embedded in architectural models. We explicitly model the implications of broadly-scoped properties, in the same way we model components, interfaces, processes, or a design space of possible architectural solutions. This externalizes architectural knowledge present in a development team or organization, and is the basis for reuse.

- *Achieving Simplicity.* Anybody can read the templates and respective composition rules in Figure 3, and understand how the team developed them. The architects do not need to change the way that they work while expressing architectural aspects. The aspectual templates can be seen as a complementary architectural view in addition to the views commonly used by the architects.

7 Aspectization of Software Architectures: Where Do We Go From Here?

The importance of software architecture to the software development process is now widely recognized. Nowadays companies rely on architectural design reviews as critical points. Architects recognize the importance of making explicit tradeoffs within the architectural design space. However, the management of broadly-scoped architectural concerns is still made in an idiosyncratic fashion, with limited support for their modular and compositional reasoning. The next 10 years of research on software

architecture will certainly have to face this problem. The marriage of software architecture and aspect-orientation is a key to address this challenge at different levels:

Identification and modeling of architectural aspects and their crosscutting decisions. The crosscutting nature of architectural decisions can manifest in several ways. As a result, architectural aspects require proper mechanisms and notations to identify, represent, and compose them.

An aspect-oriented architectural view. As the architecture of a system are represented by several views, each providing a distinct perspective of the system, the crosscutting concerns must be also modularly represented in the multi-view scenario. An aspect-oriented architectural view and the provision of multi-view "weavers" (which automate their composition) can simplify the architecting process and give a better picture of the system overall structure.

Aspectization of ADLs. There is a need for development of methodologies and tools to bridge the gap between the decisions specification and the ADL-based artifacts in order to maintain the integrity of architectural decisions. How to represent the architectural decisions at the ADL level? Although recently various proposals [4] that integrate aspect-orientation and ADLs have been emerged, they do not cope with crosscutting architectural choices. Some works extend the component-connector abstraction to represent architectural aspects and composition rules as first-class elements. Others include this concept inside the component-connector abstraction.

Assessing Aspect-Oriented Software Architectures. It is almost always cost-effective to assess the crosscutting design choices as early as possible in the life cycle. Thus, to foster the benefits of more modular software architectures, we also need architecture design analysis methods to evaluate if the architecture reflects a proper modularization and composition of architectural aspects. Traditional methods for architecture assessment, such as ATAM, can be extended to deal with those issues.

To address these challenges we can benefit from current notations, methodologies, languages, and tools and go a step further by adapting them to the new dimension of architecture design – the architectural crosscutting concerns and their composition. The adaptation of existing methodologies and tools avoid the need of the industry to deal with the burden of adopting new products in order to take advantage of the benefits of separation of concerns at the architectural level.

8 Conclusions

Architectural decisions are in the heart of the software development process because they provide the bridge between the problem space and the solution space. The promotion of modular and compositional reasoning about architectural decisions is essential to help software developers to understand if they got an architecture right according to their requirements. It is also a critical success factor for further system design and implementation. However, the broadly-scoped nature of early design choices imposes a number of problems to software engineers. In fact, architectural crosscutting concerns are even more challenging than implementation crosscutting concerns. While the latter typically impacts a single artifact (source code) often based on a single programming language, crosscutting concerns at the architectural level impacts a multitude of views with heterogeneous representations. Using only conventional approaches architects often get in trouble because important influences are scattered and tangled in the architectural views.

Based on our experience, AOSD techniques can certainly help organizations to improve their state of practice of software architecture. They support software architects with enhanced modular and compositional reasoning, which are imperative throughout all the software development phases. They also complement existing architecture-centric development approaches, both upstream and downstream. Upstream, aspect-oriented abstractions provide a natural way to modularize and compose decisions that are directly influenced by broadly-scoped concerns coming from the requirements. At the same time, downstream, explicit representation of architectural aspects facilitates the satisfaction of top-level crosscutting decisions at the detailed design and implementation stages.

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