Formalizing Architectural Patterns with the Goal-oriented Requirement Language

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Abstract. Many pattern descriptions put their emphasis on the solution to a problem rather than on often conflicting forces and how patterns balance such forces. This work uses the Goal-oriented Requirement Language (GRL) to formalize the forces of architectural patterns in a way that enables rigorous trade-off analysis while allowing the pattern user to determine the applicability of a pattern to the problem in a given context. The formalization of forces does not replace other pattern descriptions but rather complements them and relies on them to provide descriptions of the problem and solution. This work presents a description of the forces applicable in the context of architectural design, introduces how to represent patterns and forces with GRL, and then formalizes a subset of a recently published architectural pattern language.

INTRODUCTION

Patterns enable an efficient transfer of experience by documenting common solutions to recurring problems in a specific context. Much of the work on pattern documentation such as the Pattern Almanac (Rising, 2000) and pattern formalization (Taibi and Ngo, 2001) focuses on the solution domain. However, they seldom formalize the problem domain and relevant trade-offs between the various (and often conflicting) forces involved. Still, patterns need to be described and formalized in ways that enable the reader to determine whether the particular solution presented is useful and applicable to his or her problem in a given context

To address this issue, we use the Goal-oriented Requirement Language (GRL) (URN Focus Group, 2003a) to formalize pattern forces and problem domains in a way that supports a rigorous trade-off analysis. We apply this GRL-based formalization to a recently published pattern language (Avgeriou and Zdun, 2005). The pattern language covers 23 architectural patterns categorized into eight groups according to their applicability to a specific architectural view.

In the following sections, we first present the background for patterns and the formalization of patterns. Then, we introduce the GRL as part of the User Requirements Notation and our explicit model of pattern forces which provides the basis for the trade-off analysis. This is followed by the formalization of a subset of the architectural pattern language to which we have applied our approach, including a brief description of the forces applicable in the domain of architectural design. Future trends and remarks conclude this paper.

FORMALIZING PATTERNS

Patterns describe a recurring problem that occurs in a specific context and its solution (Alexander, 1979). One of their most significant contributions is that they intend to make explicit the trade-offs between the forces involved. Each pattern describes the situation when the pattern can be applied in its context. The context can be thought of as a precondition for the pattern. This precondition is further refined in the problem description with its elaboration of the forces that push and pull the system to which the pattern is applied in different directions. Here, the problem is a precise statement of the design issue to be solved. Forces are design trade-offs affected by the pattern. They can be documented in various forms. One popular approach is to document the trade-offs as sentences like "on one hand …, but on the other hand …".

The solution describes a way of resolving the forces. Some forces may not be resolved by a single pattern. In this case, a pattern often includes references to other patterns, which help resolve forces that were unresolved by the current pattern. Together, patterns connected in this way are often referred to as a pattern language. Links between patterns can be of different types, including uses, refines, and conflicts. Patterns that need another pattern link to that pattern with *uses*. Patterns specializing the context or problem of another pattern *refine* that pattern. Patterns that offer alternative solutions *conflict*.

Current pattern representations are textual. They include the Gang-of-Four (GoF) form, the Coplien form, and the Alexandrian form. The GoF form (Gamma et al., 1994) includes sections for intent, motivation, structure, participants, and collaborations. The emphasis of this format is on the structure of the solution. However, the discussion of the forces is spread out over multiple sections, which makes it challenging for a developer to get an overview of when to apply a particular pattern and the consequences of using it.

Motivated by this drawback of the GoF form, the Coplien form (Coplien, 1996) defines a more rigid pattern structure. It includes explicit sections for forces and consequences, in which the forces and the implications of using the patterns are presented in bullet form. This provides quick access to the reasons for applying a pattern. Variations of this format have been proposed that present the forces/consequences as tables.

Recently, many pattern authors have returned to the Alexandrian pattern form (Alexander, 1979). It resolves the trade-off between the needs to have structure on the one hand, and the desire to create more easily readable pieces of literature, on the other. In practical use for documenting software designs, the Alexandrian form has been adapted to include the concept of explicit lists of forces and consequences from the Coplien form.

Nonetheless, with these formats there are still open issues: how to recognize under what conditions a given pattern should be selected, how to compare between different patterns that address the same problem, and how to integrate the consequences of applying a pattern or a combination of patterns into an integrated model. It is with these issues in mind that we propose a formalization of patterns using the Goal-oriented Requirements Language in a way that supports a rigorous trade-off analysis during the application of design patterns while maintaining the generality of the solution description.

Previously, (Araujo and Weiss, 2002) have proposed an explicit representation of the forces involved in a pattern and their inter-relationships. This representation suggests interpreting forces as functional and – mainly as – non-functional requirements, and uses the Non-Functional Requirements (NFR) framework (Chung et al., 2000) to analyze forces and the trade-offs made by a pattern.

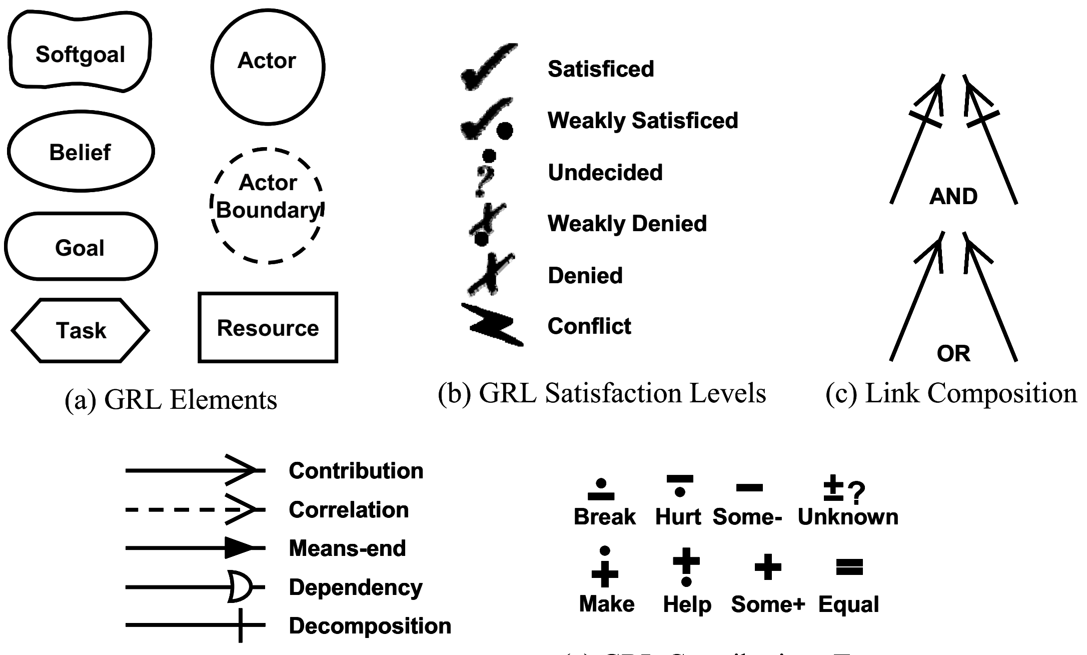
In related earlier work, (Ong, Weiss, and Araujo 2003) derived the forces affected by a pattern through a close reading of the textual pattern description. The extended pattern representation enabled them to discover contributions made by the patterns to overall system concerns that were only implicit in their textual descriptions. Their main finding was that the contributions of each pattern to overall system concerns became much more apparent than what could be gleaned from reading the pattern descriptions alone.

Our approach is similar, at the level of individual patterns, to the work by (Gross and Yu, 2001), as well as (Chung et al., 2002). Both present ways of reasoning about patterns using NFRs. However, there are important differences. We are also concerned with the connections between patterns at the pattern language level, as well as with establishing models of the forces and their trade-offs that exist in a particular domain. As a result, we feel that our results are farther-reaching, and will lead to a more objective approach.

USER REQUIREMENTS NOTATION

The *User Requirements Notation* (URN) is a standardization effort of the International Telecommunications Union (ITU) and published in the Z.150 series of Recommendations (ITU-T, 2003). URN is a high-level modeling notation that makes use of goals and scenarios to model and analyze user requirements in a more formal way. The notation is generally suitable for the description of most types of reactive, concurrent, and distributed systems and services; e.g. telecommunications systems, e-commerce systems, agent systems, operating systems, and health information systems. URN is also a convenient notation for business process modeling and evolution (Weiss and Amyot, 2005). An overview of URN with a tutorial example from the wireless communication domain is presented in (Amyot, 2003).

URN consists of two complementary notations. *Use Case Map*s (UCMs) (URN Focus Group, 2003b) allow the specification of behavior and structure. The *Goal-oriented Requirement Language* (GRL) (URN Focus Group, 2003a) represents goals and stakeholders. Both notations are useful in the context of formalizing pattern forces and solutions, and for trade-off analysis. UCMs are particularly useful for modeling structural and behavioral aspects of the solution part of patterns (e.g. the consequences of applying patterns in terms of the architectural design of a system), whereas GRL is a valuable tool to model pattern forces and their interactions. This work focuses on the later. GRL complements the NFR (Non-Functional Requirements) framework published in (Chung et al., 2000) with agent modeling concepts from the *i** framework (Yu, 1997). GRL captures business or system goals, stakeholder concerns, alternative means of achieving goals, and the rationale for goals and alternatives. Alternatives are evaluated in terms of their impact on goals and stakeholder concerns. The notation is applicable to functional requirements, but it is especially good for capturing and reasoning about the interaction of non-functional requirements. See Figure 1 for a summary of the main notation elements of GRL.



(a) GRL Elements (b) GRL Satisfaction Levels (c) Link Composition

(d) GRL Links (e) GRL Contributions Types

Figure 1. Summary of the GRL notation

FORMALIZING FORCES FOR TRADE-OFF ANALYSIS

We use GRL graphs to explicitly model the forces addressed by a pattern, the rationale behind them, the relationships between patterns, the contribution of a pattern to the system, and the stakeholders' interest in various aspects of the system. The GRL graph in Figure 2 shows the contributions of an individual pattern to its forces.

Forces are represented as softgoals (clouds), indicating that these cannot be achieved in an absolute manner. Patterns are modeled as tasks (hexagons), representing ways of achieving a softgoal. The nodes of this goal graph are connected by different types of links. Direct contributions of a pattern to softgoals are shown as solid lines. Side effects (indirect contributions called correlations) are shown as dotted lines. The kind of contribution is determined by labels, indicating various degrees of positive (+) or negative (-) contributions (see Figure 1e for the complete set of labels). The complexity of the system dictates the number of levels of forces (e.g. two in Figure 2), but there is at least one level of forces.

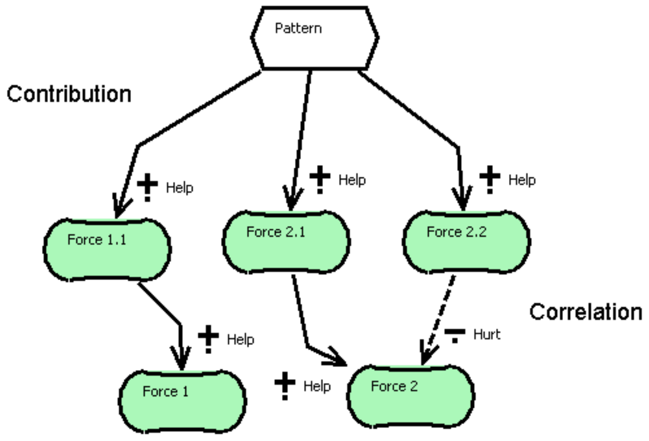


Figure 2. Modeling individual pattern – Alternative 1

Observation 1. There is only a subtle difference between forces and non-functional requirements. This difference manifests itself in non-functional requirements being at the top of the hierarchical structure of forces (i.e. at the bottom of Figure 3). The reason for this arrangement is that forces push or pull the system towards or away from non-functional requirements (e.g. better performance or greater security). As forces connect patterns and non-functional requirements, they provide an explanation of why a pattern impacts a non-functional requirement the way it does.

Therefore, model non-functional requirements also with softgoals. Show them on the same GRL graph in order to provide a visual connection between a pattern and the non-functional requirements addressed by the pattern. There is always one level of non-functional requirements in the GRL graph of an individual pattern. With tool support, the relationships between forces and non-functional requirements could be defined on a separate GRL graph and then automatically added to the GRL graphs for individual patterns in Figure 2.

Observation 2. A functional requirement can be addressed by many different alternative patterns. Each one of these patterns is described on its own GRL graph. Furthermore, functional requirements should be included in the goal hierarchy defined by patterns, forces, and non-functional requirements in order to assess impacts of patterns on functional as well as non-functional requirements.

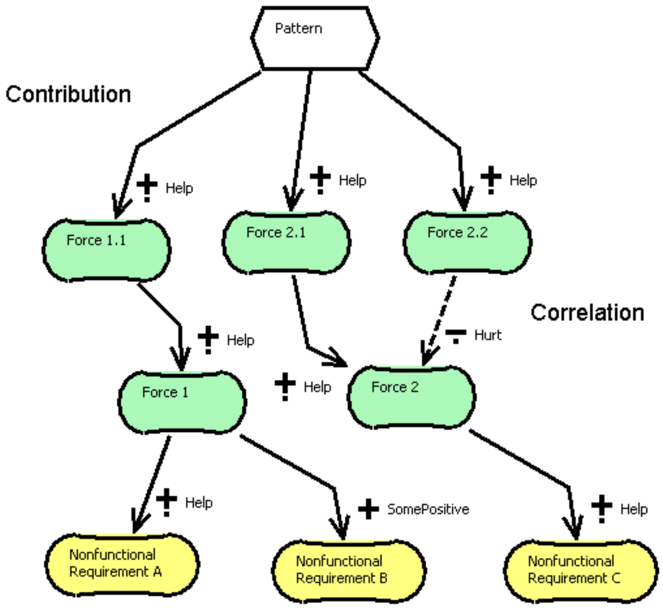


Figure 3. Modeling individual pattern – Alternative 2

Therefore, show the functional requirement on the GRL graph for individual patterns and always model the relationship between a pattern and the functional requirement to which it contributes as an OR decomposition link (barred lines). This is required due to the following reasons. On each GRL graph, the functional requirement references the same model element in GRL. Therefore, an OR decomposition has to be used instead of an AND decomposition because any one of the individual patterns can satisfy the functional requirement. An AND decomposition (even if it is distributed over many GRL graphs), on the other hand, would mean that all patterns are required in the system design before the functional requirement is satisfied. This is often the case as only a pattern combination may achieve a particular functional requirement, but it is modeled in a different way in our approach as explained later in this section.

Functional requirements are represented as (hard) goals (rounded rectangles) in order to indicate that the functional requirement can be satisfied in an absolute manner. Goals allow us to reason about the functional requirements to which a pattern contributes. Functional requirements are shown at the top of Figure 4.

Even though our examples only show one functional requirement on the GRL graphs for individual patterns, our pattern representation is not at all limited to just one such goal. Many different goals describing many different functional requirements may be shown on a GRL graph and may be connected with decomposition links to individual patterns.

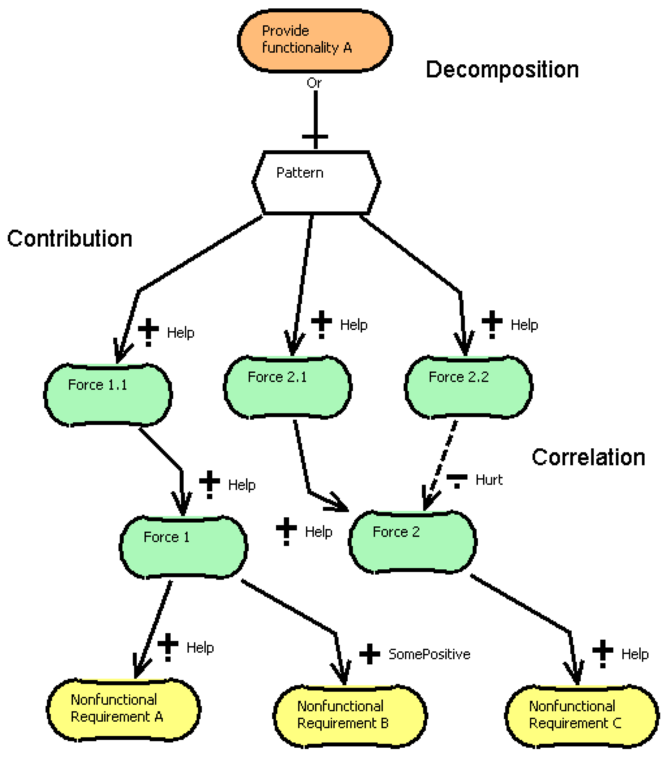


Figure 4. Modeling individual pattern – Alternative 3

Observation 3. Often, an individual pattern makes use of other patterns. The contributions of these patterns to functional and non-functional requirements have already been defined on their individual GRL graphs. They should only be created once.

Therefore, show the composition of pattern with decomposition links on the GRL graph of the individual pattern. Figure 5 constitutes the complete structure of the GRL graph for an *individual pattern*.

Decomposition links between tasks allow various relationships between patterns to be modeled (e.g. uses, refines, and conflict relationships). Figure 5 shows that “Pattern” uses “Pattern A” and “Pattern B”. The impact of “Pattern A” and “Pattern B” on forces, non-functional requirements, and functional requirements is shown on their own individual GRL graphs. Therefore, GRL graphs for an individual pattern establish reusable models of forces applicable to many domains.

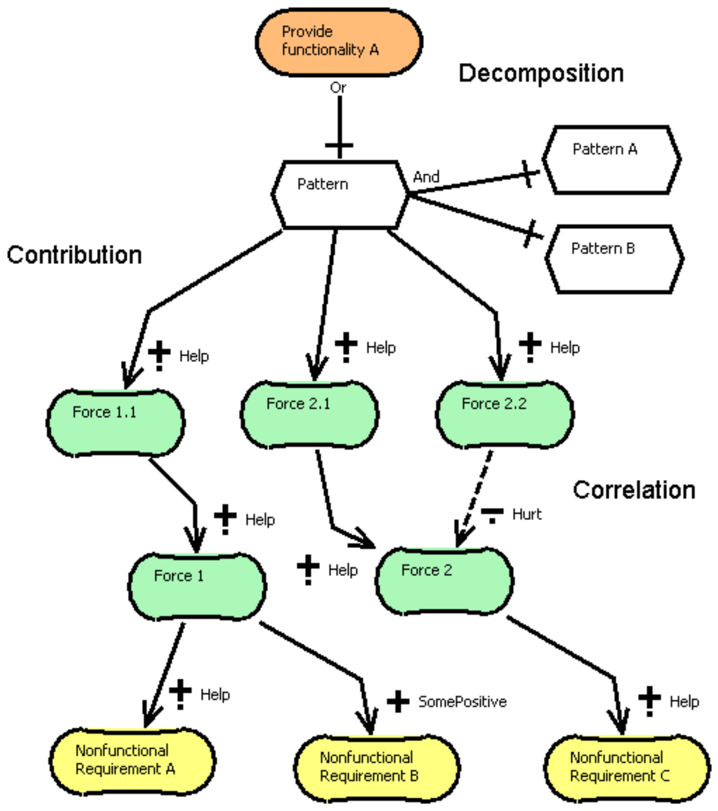


Figure 5. Modeling individual pattern

Observation 4. If a pattern combination is a pattern in itself, then the GRL graph for individual patterns is used to describe the pattern combination (see Figure 5). A pattern combination, however, may not be a pattern in itself, but may just represent the usage of several patterns together. Considering the composite pattern, there should not be a difference in our representation between an actual pattern and a pattern combination. Patterns and pattern combinations should be used interchangeably, allowing both to be considered as alternatives for a functional requirement. However, if a pattern combination is not a pattern, then there is no need to model forces and the impact of forces on non-functional requirements.

Therefore, simplify the GRL graph for an individual pattern into the GRL graph for a *pattern combination* (see Figure 6). Figure 6 addresses the point in observation 2 regarding AND decompositions of a functional requirement into many patterns ("Pattern A" and "Pattern B") by explicitly modeling the pattern combination as a task ("Pattern Combination").

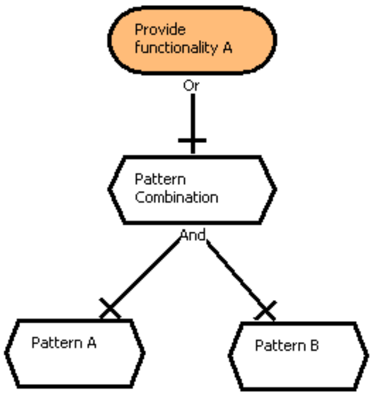


Figure 6. Modeling pattern combinations

Observation 5. A GRL graph for an individual pattern shows all forces and non-functional requirements impacted by the pattern, irrespective of the current system to be designed. Not all non-functional requirements, however, may be of interest to stakeholders in the context of any specific system design task. As it should be possible to reuse these graphs as is for each system to be designed, the stakeholders' interest in particular non-functional requirements has to be modeled with additional GRL graphs.

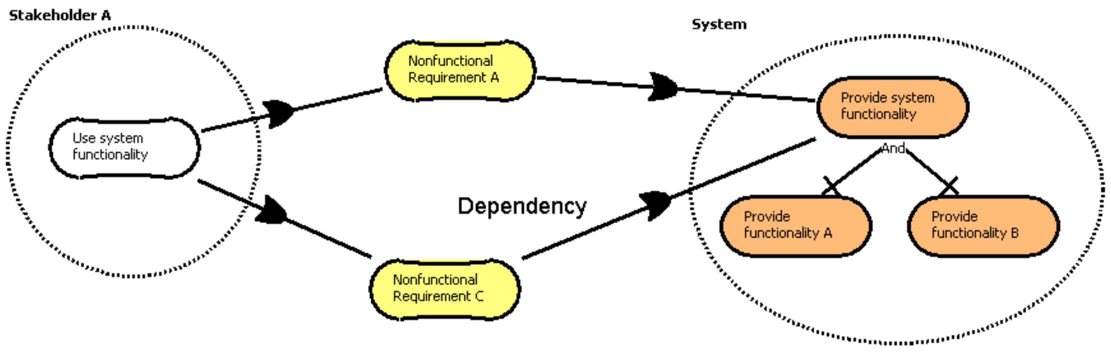


Figure 7. Modeling stakeholder concerns

Therefore, the stakeholders of a system and the system itself are modeled as GRL actors (dotted circles) with dependency links (lines with filled direction symbol) between them identifying only the non-functional requirements of interest to a particular stakeholder. The GRL graph for *stakeholder concerns* in Figure 7 shows that stakeholder A depends on the system to provide "Nonfunctional Requirement A" and "Nonfunctional

Requirement C". Note that dependency links may connect non-functional requirements with subgoals instead of the main functional goal as shown in Figure 7.

Like most goal-oriented languages, GRL supports propagation algorithms to evaluate, for a given *strategy*, to what degree the goals and softgoals in a model are satisfied (URN Focus Group, 2003a). A strategy assigns initial satisfaction values to some of the elements in the model which are then propagated to the other elements connected by contribution, correlation, and decomposition links. This enables one to make a qualitative, rapid, and global assessment of the impact of a particular choice and hence to find the most appropriate trade-off in a given context.

Observation 6. Our pattern representation consists of two hierarchies – one for non-functional requirements and one for functional requirements. The top level of both hierarchies is shown on the GRL graph for stakeholder concerns. The main functional requirements are refined into subgoals until a subgoal can be addressed by a pattern or pattern combination (e.g. one subgoal could be that the system needs to process streams of data which is addressed by patterns in the Data Flow View group of the architectural pattern language). This subgoal is then referenced on GRL graphs of applicable individual patterns or pattern combinations, and decomposed with an OR decomposition into the pattern or pattern combination, respectively. Non-functional requirements are also referenced on the GRL graphs of applicable individual patterns or pattern combinations. They are connected via contribution or correlation links to forces which in turn are eventually connected to the pattern or pattern combination, respectively.

Therefore, patterns and pattern combinations are at the bottom of both hierarchies and represent possible solutions to functional and non-functional requirements. Furthermore, the patterns and pattern combinations are also the model elements to which initial satisfaction values for the propagation algorithm should be assigned in order to evaluate alternate solutions. The initial values are propagated upwards the hierarchies to the GRL graph for stakeholder concerns where the final evaluation is shown. The two hierarchies ensure that the chosen solution is evaluated in terms of its impact on functional and non-functional requirements, avoiding cases where a solution satisfies only functional requirements at the cost of non-functional requirements or vice versa. Note that the propagation algorithm combines the contributions of several patterns or pattern combinations to a particular non-functional requirement even if the contributions to the non-functional requirement are shown on several GRL graphs. The combined result is global and shown on each GRL graph.

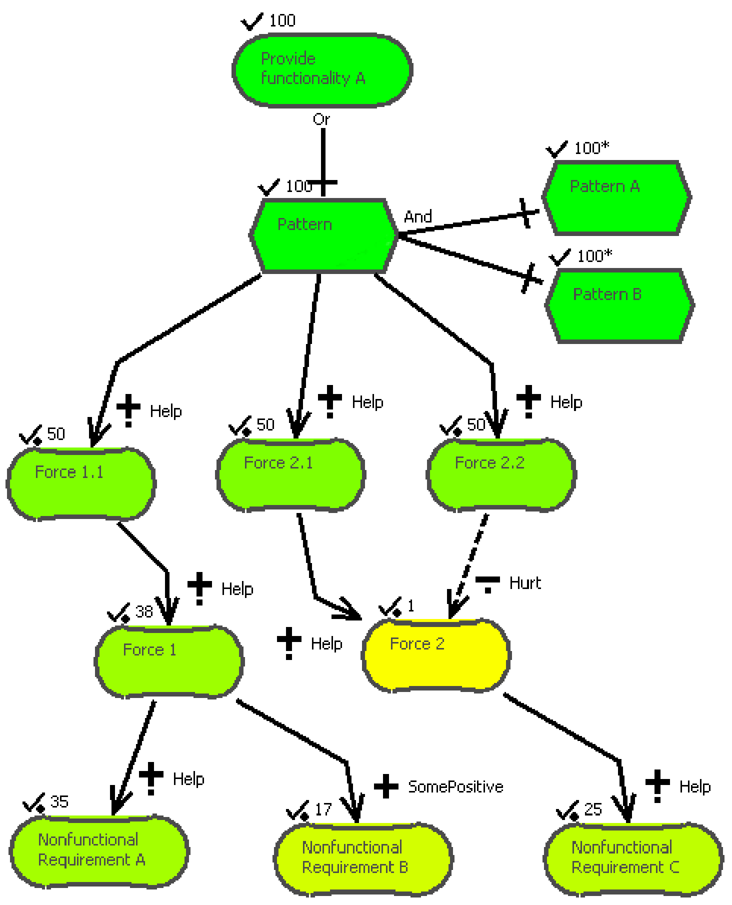


Figure 8. Investigating the impact of a pattern

Figure 8 shows the evaluation of an individual pattern with regards to its forces, functional requirements, and non-functional requirements. The evaluation results are indicated for each node of the goal graph with various checkmarks (positive) and crosses (negative) (see Figure 1b for the complete set of evaluation results) as well as numbers between -100 (denied) and 100 (satisfied). Initial values are marked with a star (*) on the evaluation diagram. Note that in order to assess the full impact of the individual pattern, all patterns used by the individual pattern (i.e., “Pattern A” and “Pattern B”) must have their initial satisfaction values set to 100. This ensures that the contributions of the patterns used by the individual pattern are taken into account for the evaluation of forces, non-functional requirements, and functional requirements. If the initial satisfaction values of “Pattern A” or “Pattern B” are changed in Figure 8, the results for those forces, non-functional requirements, and functional requirements that also occur on the individual GRL graphs for “Pattern A” or “Pattern B” will be different.

Finally, Figure 9 shows the evaluation results from the stakeholder’s point of view. The evaluation value of the main functional goal of the system is calculated (in this case it is not satisfied because only one of the two subgoals is satisfied) and the evaluation values of the non-functional requirements the stakeholder is interested in are shown. Note that these values match the values on the GRL graphs for individual patterns or pattern combinations.

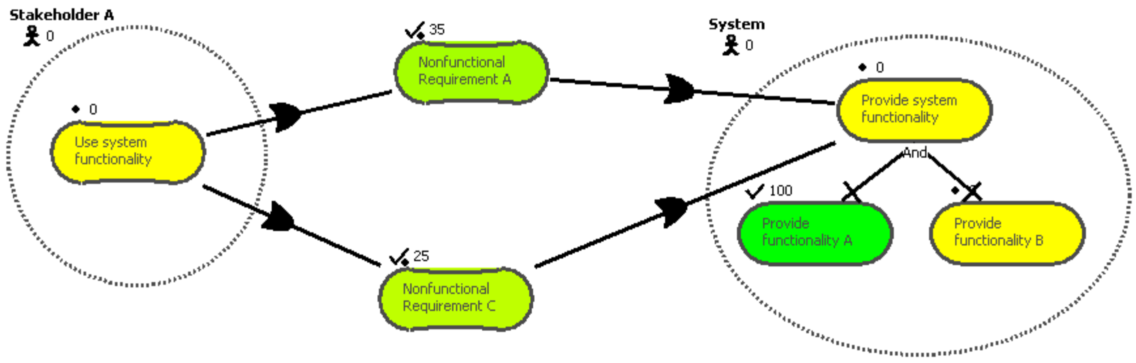


Figure 9. Assessing evaluations from the stakeholder’s point of view

Observation 7. As with all modeling techniques, the usefulness of our technique presented in this section depends on how easily the technique can be included into general software development processes. A pre-condition to our technique is that regular pattern descriptions are extended to include our formalized, reusable description of pattern forces as suggested in this section (see Figure 5). Note that the presence of our GRL models does neither preclude the existence of other representations and formalizations nor does it require a particular pattern template.

Therefore, indicate what changes are most likely required to incorporate our technique into a general software development process.

1. Compile a list of stakeholders for the system. This process step should already be in place.
2. For each stakeholder, create a GRL graph for stakeholder concerns by identifying the non-functional requirements of interest to the stakeholder (see Figure 7; space permitting, more than one stakeholder may be shown on one GRL graph). The

identification of stakeholder concerns should already be a part of the process but visual modeling is an addition.

3. Refine the system's main functional goal into subgoals. This step also should be in place and again is done additionally in a visual way. Two cases have to be considered at this step:
    a. If the subgoal matches a functional goal identified in the pattern catalogue on one of the GRL graphs for individual patterns or pattern combinations, it is very likely that the subgoal does not need to be refined further. The list of goals identified in the pattern catalogue can actually be used to guide the refinement of goals.
    b. If the subgoal does not match a functional goal identified in the pattern catalogue, then again there are two choices:
        i. Further refine the subgoal until the refinement produces a matching subgoal.
        ii. Stop refinement of the subgoal and create a new pattern combination (see Figure 6) that addresses the specific need of this subgoal. A recurring, new pattern combination may even lead to a new pattern to be added to the pattern catalogue.
        iii. Stop refinement of the subgoal and address the subgoal with a solution that does not make use of patterns. The impact of this particular solution on functional and non-functional requirements can still be modeled. This, however, is only necessary if we are concerned with modeling the complete system regardless of whether patterns are used or not. If our goal is to "only" compare alternative patterns, indicate the trade-offs, and provide assistance in choosing the best pattern for the given subgoal, then we may not need to be concerned about non-pattern choices.
4. Connect the main goal or relevant subgoals with the stakeholder's non-functional requirements. In a general software development process, this is most likely not done explicitly to the extent required by our technique.
5. Determine the most suitable pattern or pattern combination by using tool-supported trade-off analysis based on GRL strategies. This is currently done in an ad-hoc manner in the worst case and with tool support in the best case.

The focus of the suggested process is on comparing patterns. The comparison simply shows the different impact the patterns have. It captures the information that is currently provided in the forces and consequences sections of a pattern description. The visualization, however, allows us to more readily see what impact the selection of a pattern or a group of patterns will have. The context for the pattern is defined by prioritizing the non-functional requirements (see step 2), thereby adapting the pattern to the environment. As indicated earlier on, our approach does not model the solution part of a pattern which is arguably the part where most of the variations happen when a pattern is used in a new context. The approach focuses on the more stable part of the forces and relationships between forces. By understanding the interaction of forces, the user is given the groundwork required to adapt the pattern in a new situation.

FORMALIZING ARCHITECTURAL PATTERNS

Observation 8. The bottom half of Figure 3 suggests that there are relationships between forces and non-functional requirements that are independent of patterns.

Therefore in this section, we formalize the relationship between forces and non-functional requirements in the domain of architectural design based on the discussion of eight non-functional requirements in chapter 2 of (Dyson and Longshaw, 2004):

1. Availability (see Figure 10) – the "working hours" of the system (the amount of time the system is up and running).
2. Performance (see Figure 11) – ability of the system to provide a timely response.
3. Scalability (see Figure 12) – ability to ensure performance when the number of users grows.
4. Security (see Figure 13) – ability to ensure access control and privacy of information.
5. Manageability (see Figure 14) – ability to monitor and adjust the system's runtime behavior.
6. Maintainability (see Figure 15) – the ease with which problems are fixed.
7. Flexibility (see Figure 16) – the ease with which new functionality and new non-functional characteristics are provided for a system.

8. Portability (see Figure 16) – the ease with which a system is migrated to a new operating environment.

Figure 10 to Figure 16 depict the forces and how each force impacts another force or non-functional requirement as mentioned in chapter 2 of (Dyson and Longshaw, 2004). The set of forces is not necessarily complete as it only reflects the forces mentioned by (Dyson and Longshaw, 2004). Other authors may want to add additional forces or relationships. The GRL graphs, however, make these forces and relationships more explicit, allowing easier identification and addition of other forces.

Reflecting the nature of forces at play for architectural design, the forces in the GRL graphs are at different levels of abstraction and cover very different things (e.g. “More robust against failure” and “Average number of users increases with time”). The GRL graphs do not prescribe a certain level of abstraction and can certainly cover very different things, because the goal of GRL graphs is to show all issues that have to be considered in a certain situation and how these issues interact with each other. The degree of contribution is used to show the importance of a force.

If the meaning of one force is not clear from its label, it is often helpful to look at the forces that contribute to the force. Alternatively, a more elaborate description or definition can be attached to the force.

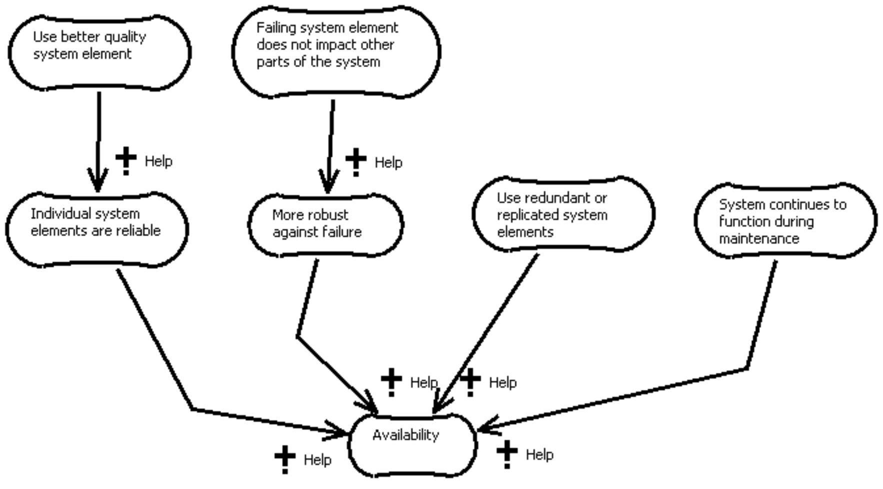

Use better quality system element
Failing system element does not impact other parts of the system
Help
Help
Individual system elements are reliable
More robust against failure
Use redundant or replicated system elements
System continues to function during maintenance
Help
Help
Availability
Help
Help

Figure 10. Forces of architectural design that impact availability

Reading the GRL graphs reveals the forces in the architectural domain. For example, Figure 10 indicates that “Use redundant or replicated system elements HELPs availability.” The whole sentence expresses an invariant, consisting of a force and, in this case, its impact on a non-functional requirement. The invariant has to be considered and understood for the domain in question. The wording of a force can be a matter of discussion. Some styles prefer the force to be worded with a keyword (similar to requirements, e.g. shall). Such styles can certainly be incorporated into our formalization. The main point is that the GRL graphs clearly identify forces, enabling a discussion on wording, etc.

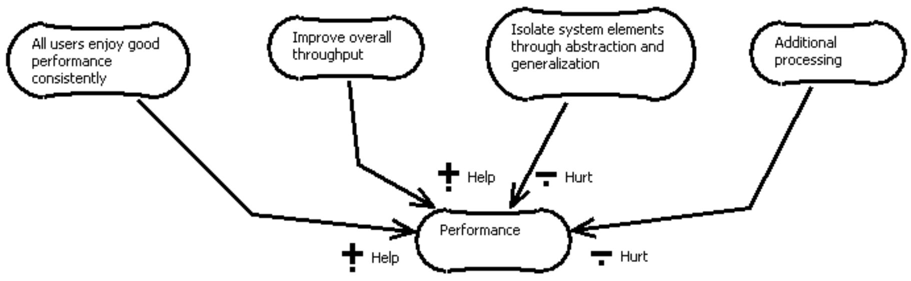

All users enjoy good performance consistently
Improve overall throughput
Isolate system elements through abstraction and generalization
Additional processing
Help
Hurt
Performance
Help
Hurt

Figure 11. Forces of architectural design that impact performance

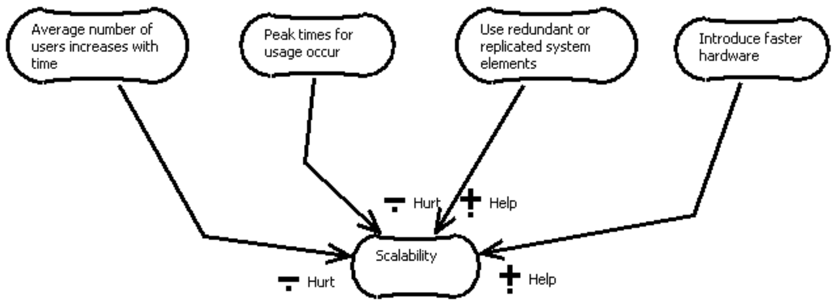

Average number of users increases with time
Peak times for usage occur
Use redundant or replicated system elements
Introduce faster hardware
Hurt
Help
Scalability
Hurt
Help

Figure 12. Forces of architectural design that impact scalability

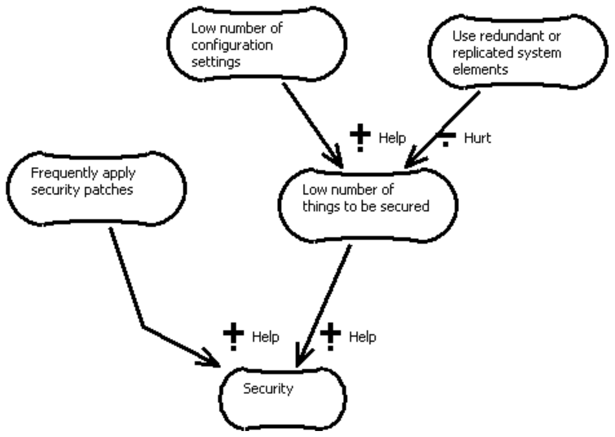

Low number of configuration settings
Use redundant or replicated system elements
Help
Hurt
Frequently apply security patches
Low number of things to be secured
Help
Help
Security

Figure 13. Forces of architectural design that impact security

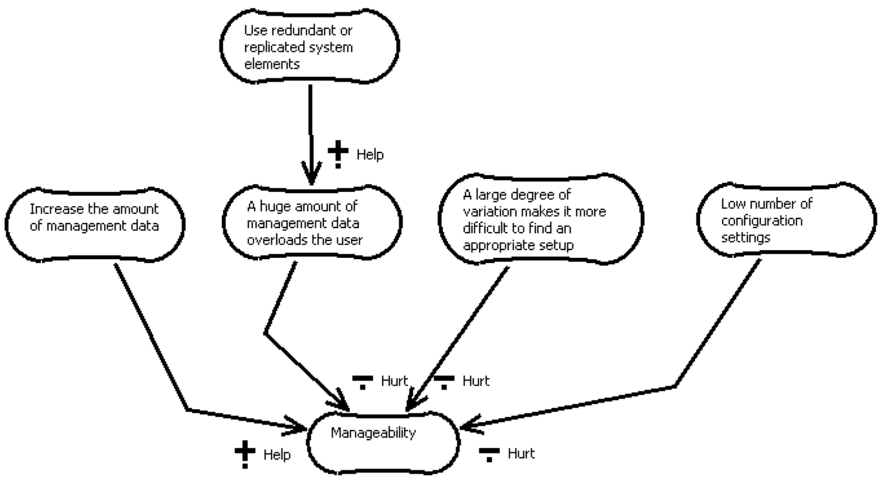

Use redundant or replicated system elements
Help
Increase the amount of management data
A huge amount of management data overloads the user
A large degree of variation makes it more difficult to find an appropriate setup
Low number of configuration settings
Hurt
Hurt
Manageability
Help
Hurt

Figure 14. Forces of architectural design that impact manageability

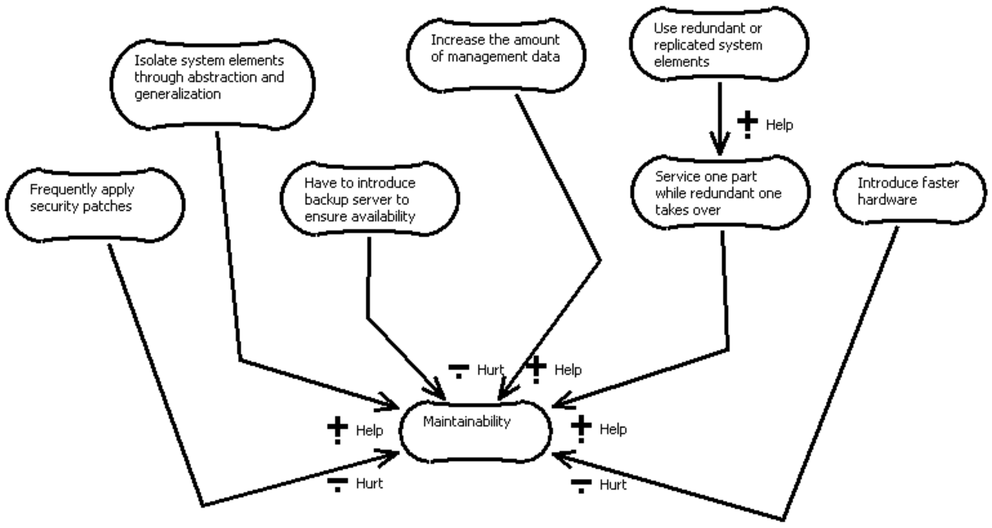

Isolate system elements through abstraction and generalization
Increase the amount of management data
Use redundant or replicated system elements
Help
Frequently apply security patches
Have to introduce backup server to ensure availability
Service one part while redundant one takes over
Introduce faster hardware
Hurt
Help
Maintainability
Help
Help
Hurt
Hurt

Figure 15. Forces of architectural design that impact maintainability

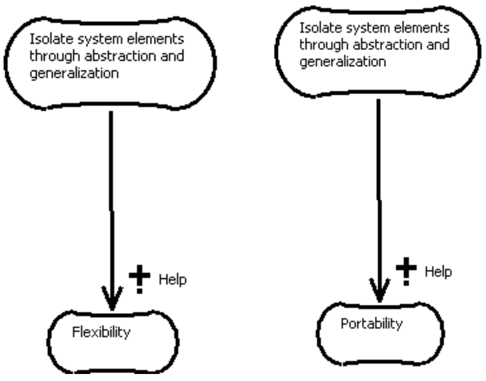

Isolate system elements through abstraction and generalization
Isolate system elements through abstraction and generalization
Help
Help
Flexibility
Portability

Figure 16. Forces of architectural design that impact flexibility and portability

As an example, we have applied our pattern formalization to one of the architectural views described in (Avgeriou and Zdun, 2005). The Layered View is concerned with how interacting parts of a system remain decoupled. Two patterns are classified under the Layered View: Layers and Indirection Layer (see Figure 17).

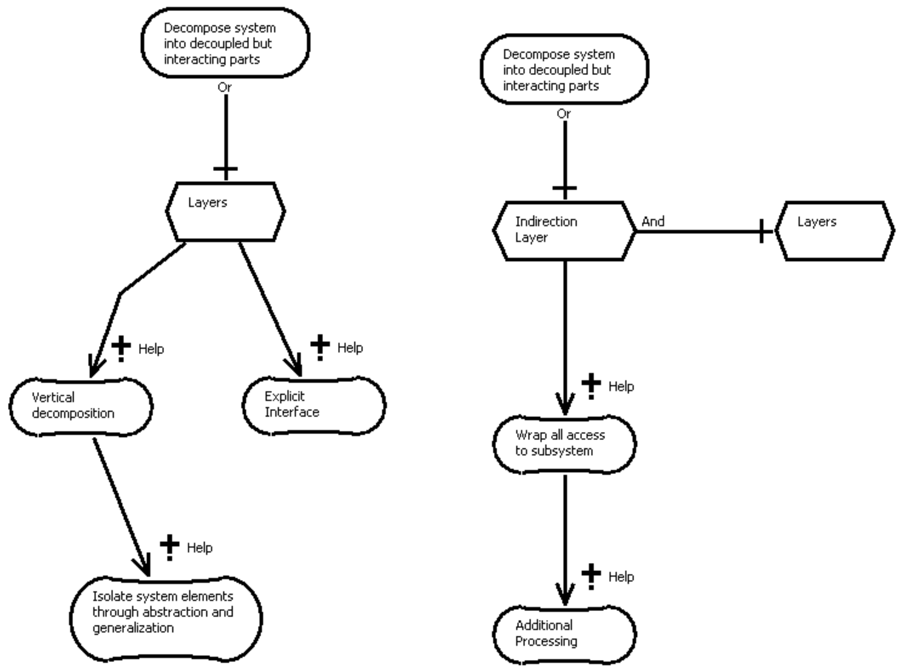

Decompose system into decoupled but interacting parts
Or
Layers
Help
Help
Vertical decomposition
Explicit Interface
Help
Isolate system elements through abstraction and generalization
Decompose system into decoupled but interacting parts
Or
Indirection Layer
And
Layers
Help
Wrap all access to subsystem
Help
Additional Processing

Figure 17. Layers (left) and Indirection Layer (right)

Figure 17 helps us conclude that the patterns impact performance more or less negatively and maintainability, flexibility, and portability positively because it references the softgoals “Isolate system elements through abstraction and generalization” and “Additional Processing” which also occur in Figure 11, Figure 15, and Figure 16.

Figure 10 to Figure 17 represent one complete view of the system in terms of forces and non-functional requirements. Other views, however, can be created if they are deemed useful by rearranging the forces and non-functional requirements. The relationship between the pattern “Layers” and the non-functional requirements performance, maintainability, flexibility, and portability is shown indirectly in Figure 17 with the help of the referenced softgoal “Isolate system elements through abstraction and generalization”. In this case, the organization of the GRL graphs favors reusability of the graphs in Figure 10 to Figure 16 over directly showing, on a single GRL graph, the impact of the pattern “Layers” on non-functional requirements. The latter view, however, can be easily created from the presented GRL graphs.

DISCUSSION AND FUTURE TRENDS

This example demonstrates how GRL graphs capture pattern forces and can be used to assess the qualitative impact of various solutions to a functional goal, in context. The benefits of the proposed process become even more interesting as the system gets more complex and trade-offs are more difficult to assess due to numerous interrelated contributions and side-effects.

The proposed process for URN-based trade-off analysis is not limited to individual subgoals. It can easily be extended to pattern combinations addressing all subgoals at once, hence providing for global impact analysis and guidance, at the system level. This may go beyond the needs of designers and system architects who may only be interested in solving a focused design problem, but this level of evaluation is nevertheless possible.

Obviously, in addition to having patterns formalized with URN, the more advanced benefits require additional investments that not all modelers may be willing to make: a system-level GRL model for assessing the global impact of selected patterns.

There is also a general trend towards formalizing aspects of patterns, whether they are related to the relationships between patterns, or to properties of individual patterns. Often, these efforts have been confined to certain domains, which are more amenable to formalization, such as the area of security patterns. One example is the formalization of security properties that are satisfied by application of a pattern (Wassermann and Cheng, 2003), another is the formalization of security pattern properties in (Mouratidis et al., 2005), which allows the authors of a pattern language to assess the completeness of the language. In this work, the pattern solutions are modeled in agent-oriented models in the Tropos modeling framework. A formal language for Tropos models is used to formalize the problems, solutions, and consequences of these patterns. These properties are expressed in logic statements over the components of the solutions. Some of this logic-based formalization could be added to GRL, although it does not appear essential in our current trade-off analysis context.

Aspects, which are concerns that crosscut dominant decompositions, represent another trend identifiable in the software community in general. Aspects have been studied for a decade and are used to compensate several weaknesses of object-oriented programming languages (e.g., scattering and tangling of functionalities and other concerns). Existing design patterns have been recast for new aspect-oriented languages, e.g. see (Hannemann and Kiczales, 2002), whereas new patterns specific to such languages have started to appear. More recently, aspect-oriented concepts have been included in modeling languages, closer to design and requirements. For instance, (Jacobson and Ng, 2004) present an approach where aspects are derived from UML use cases, whereas (Yu et al., 2004) present an approach where aspects are inferred from goal models. The impact of the availability of such enhanced modeling languages requires further exploration. For instance, we believe aspect-oriented concepts can easily be added to URN. This could help close the gap between aspect-oriented modeling and programming languages and at the same time open the door to new types of patterns that are more abstract or closer to requirements than the current generation of design patterns.

CONCLUSION

In this paper, we have presented an approach where architectural patterns are formalized with the Goal-oriented Requirements Language (GRL). Our main objective is to describe patterns in a way that the various and conflicting forces involved can guide, in a given context, the selection of the most suitable patterns or combinations of patterns amongst many alternatives.

Forces and contributions for individual patterns are captured using GRL. Combinations and side effects (correlations) are described with AND graphs, and alternative combinations for a given (functional) goal are represented with an OR graph. With the help of strategies (i.e. initial selections of candidate patterns) and propagation rules, designers can assess the impact of their selection on the forces and find a suitable solution in their context. This context can itself be modeled with GRL, first at the actor/dependency level and then at the level of intentional elements (goals, softgoals, tasks, etc.) for the system. This enables global and rigorous assessments to be made, even when many functional sub-goals are considered.

To take full advantage of URN-based formalization of design patterns, a process was briefly introduced and illustrated with a case study where many combinations of patterns could be used to achieve the same functionality while leading to different trade-offs involving non-functional aspects such as maintainability and performance. A prototype Eclipse plug-in, which was used to create and evaluate the URN models presented here, already exists to support such process, and is still evolving to support new types of analyses and transformations (Roy et al., 2006).

We believe this formalization approach will provide means to get rapid and global trade-off analysis results in context and make better use of current and future design patterns.

REFERENCES

Alexander, C. (1979). *A Pattern Language*. Oxford University Press.

Amyot, D. (2003). Introduction to the User Requirements Notation: Learning by Example. *Computer Networks*, 42(3), 285-301.

Araujo, I., and Weiss, M. (2002). Linking Non-Functional Requirements and Patterns. *Conference on Pattern Languages of Programs (PLoP).* Electronic Proceedings, jerry.cs.uiuc.edu/~plop/plop2002 (last accessed Nov. 2005).

Avgeriou, P., and Zdun, U., (2005). Architectural Patterns Revisited - A Pattern Language. *Tenth European Conference on Pattern Languages of Programs (EuroPlop)*, Irsee, Germany, July.

Chung, L., Nixon, B., Yu, E., and Mylopoulos, J. (2000). *Non-Functional Requirements in Software Engineering.* Kluwer Academic Publishers.

Chung, L., Supakkul, S., and Yu, A. (2002). Good Software Architecting: Goals, Objects, and Patterns. *Information, Computing & Communication Technology Symposium (ICCT- 2002), UKC'02*. Seoul, Korea, July 8-11.

Coplien, J. (1996). *Software Patterns.* SIGS. Available electronically: http://users.rcn.com/jcoplien/Patterns/WhitePaper/SoftwarePatterns.pdf (last accessed March 2006).

Dyson, P. and Longshaw, A. (2004). *Architecting Enterprise Solutions – Patterns for High-Capability Internet-Based Systems*. John Wiley & Sons, Ltd, 364 pages.

Gamma, E., Helm, R., Johnson, R., and Vlissides, J. (1994). *Design Patterns: Elements of Reusable Object-Oriented Software.* Addison-Wesley.

Gross, D., and Yu, E. (2001) From Non-Functional Requirements to Design through Patterns. *Requirements Engineering*, 6(1), 18-36, Springer.

Hannemann, J. and Kiczales, G. (2002) Design Pattern Implementation in Java and AspectJ*, 17th OOPSLA*, November, 161-173.

ITU-T (2003). *Recommendation Z.150 (02/03), User Requirements Notation (URN) – Language Requirements and Framework.* Geneva, Switzerland.

Jacobson, I. and Ng, P.-W. (2004). *Aspect-Oriented Software Development with Use Cases*, Addison Wesley Professional.

Mouratidis, H., Weiss, M., and Giorgini, P. (2005). Security Patterns Meet Agent Oriented Software Engineering: A Complementary Solution for Developing Secure Information Systems. *Conceptual Modeling (ER)*. LNCS 3716, 225-240, Springer.

Ong, H., Weiss, M., and Araujo, I. (2003). Rewriting a Pattern Language to Make it More Expressive. *Hot Topic on the Expressiveness of Pattern Languages, ChiliPLoP*. Carefree, USA, March.

Rising, L., (2000). *Pattern Almanac 2000*. Addison-Wesley.

Roy, J.-F., Kealey, J. and Amyot, D. (2006). Towards Integrated Tool Support for the User Requirements Notation. To appear in *SAM'2006*, Kaiserslautern, Germany.

Taibi, T. and Ngo, D.C.L. (2001). Why and How Should Patterns Be Formalized. *Journal of Object-Oriented Programming (JOOP)*, vol. 14, no 4, 8-9.

URN Focus Group (2003a). *Draft Rec. Z.151 – Goal-oriented Requirement Language (GRL).* Geneva, Switzerland, Sept. 2003.

URN Focus Group (2003b). *Draft Rec. Z.152 – Use Case Map Notation (UCM).* Geneva, Switzerland, Sept. 2003.

Wassermann, R., and Cheng, B. (2003). *Security Patterns*. Technical Report, MSU-CSE-03-23, Michigan State University.

Weiss, M. and Amyot, D. (2005). Business Process Modeling with URN. *International Journal of E-Business Research*, 1(3), 63-90, July-September.

Yu, E. (1997). Towards Modelling and Reasoning Support for Early-Phase Requirements Engineering. *Proceedings of the 3rd IEEE International Symposium on Requirements Engineering (RE'97)*. Jan. 6-8, Washington D.C., USA, 226-235.

Yu, Y., Leite, J.C.S.P., and Mylopoulos, J. (2004). From Goals to Aspects: Discovering Aspects from Requirements Goal Models. *12th IEEE Int. Conf. on Requirements Engineering (RE 2004)*, Kyoto, Japan, September, 38-47.