Requirement Engineering with URN: Integrating Goals and Scenarios

Jean-François Roy

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Abstract

The User Requirements Notation (URN) is an emerging standard that combines two views: the Goal-oriented Requirement Language (GRL) and the Use Case Map (UCM) notation. This standard intends to combine goals and scenarios for expressing and reasoning about functional and non-functional requirements. Although tools exist in isolation for both views, they are currently not meant to work together, hence hindering the development and adoption of URN. This thesis presents Eclipse-based tool support for integrated goal and scenario modelling based on URN. A metamodel that integrates GRL with an existing UCM metamodel is given, together with a detailed description of the tool capabilities. New and automated analysis approaches are also introduced, which exploit integrated URN models. The approaches that are described include quantitative goal evaluations, stakeholder evaluations, novel GRL strategies, and links between the URN views. In addition, this thesis presents an approach to link GRL models to external requirements, also supported by our tool. Finally, the integrated URN approach is illustrated and validated using case studies.

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Table of Contents

List of Figures

List of Tables

List of Acronyms

Acronym	Definition
API	Application Programming Interface
DSML	Domain-Specific Modelling Language
EMF	Eclipse Modeling Framework
FR	Functional Requirements
GEF	Graphical Editing Framework
GRL	Goal-oriented Requirement Language
jUCMNav	Java Use Case Maps Navigator
LQN	Layered Queuing Networks
MDA	Model Driven Architecture
MDD	Model Driven Development
MSC	Message Sequence Chart
MVC	Model-View-Controller
NFR	Non-Functional Requirements
RE	Requirement Engineering
RMS	Requirements Management System
SD	Strategic Dependencies
SIG	Softgoal Interdependencies Graph (in NFR framework)
SR	Strategic Rationales
UCM	Use Case Maps
UCMNav	Use Case Maps Navigator
UML	Unified Modeling Language
URN	User Requirements Notation
URN-FR	User Requirements Notation – Functional Requirement Notation
URN-NFR	User Requirements Notation – Non-Functional Requirement Notation
XMI	XML Metadata Interchange
XML	Extensible Markup Language

Chapter 1 Introduction

This thesis presents Eclipse-based tool support for integrated goal and scenario modelling based on the User Requirement Notation (URN) [24]. URN is an emerging standard that combines two views: the Goal-oriented Requirement Language (GRL) [25] and the Use Case Map (UCM) notation [11][12][26]. Tools exist for both views but only in isolation, hence preventing modellers from exploiting URN to its fullest extent. This thesis also introduces new and automated analysis approaches that use links between the two URN views. Finally, this thesis presents an approach to link GRL models to external requirements, also supported by our tool.

1.1 Motivation

Requirement engineering is concerned with real-world goals, functions, and qualities of (software) systems, the relationship between these factors, and their specification as they evolve over time [68]. Requirements are generally categorized as functional or non-functional. Functional requirements describe what systems must do whereas non-functional requirements describe qualities and constraints associated with systems.

Over the years, various techniques were proposed to deal with one or many requirement engineering activities, including requirements elicitation, analysis, specification, verification and management [10][41]. Earlier software requirements engineering techniques were developed based on structural programming or object-oriented approaches. However, to capture declarative, behavioural and interactive aspects of systems, goal-oriented requirements analysis has been proposed more recently [38]. Using goals as the main requirement constructs, these analysis methods allow exploration of alternatives, decision spaces, and tradeoffs by considering questions such as “why”, “how” and “how else” [65] instead of only considering functional concerns.

On top of goal analysis modelling, agent-oriented requirements engineering [62][64] was developed to further consider the environment of systems. To represent active elements in their environment, agents (humans or systems) have associated respon-

sibilities and constraints in their interactions. Essential concepts such as functionality, quality and process are organized around agents. This requirement modelling approach offers a higher level of abstraction for describing desired software systems [32].

On the other hand, scenarios modelling approaches [3] were developed to describe functional and operational requirements. In addition, these techniques are helpful for uncovering hidden requirements, and for validating/verifying requirements. Compared with goals, scenarios are easier to provide and understand for many stakeholders.

Even if the problem of managing functional and non-functional requirements together is well known, only a few techniques address this problem by combining the strengths of goals and scenarios [46][51]. However, solid tools allowing requirement modellers to edit and analyze integrated goal/scenario models are currently unavailable.

1.2 Thesis Goals

Given the high potential of an approach that would combine goals and scenarios for expressing and reasoning about functional and non-functional requirements, and the unavailability of appropriate integrated tool support, the main goal of this thesis is to produce a tool that would fill this undesirable gap, especially in the context of the User Requirements Notation.

In this thesis, we suppose that goals and scenarios are part of a modelling process and are used mainly between textual user requirements and detailed behavioural models. In addition, we suppose that these models are developed using an iterative approach, in parallel with models at higher and lower levels of abstraction. Therefore, such models will require update mechanisms that support traceability and evolving requirements. Developing synchronization support between URN and external models should enable the usage of URN models in all phases of the requirement engineering process.

1.3 Contributions

The following contributions, related to the combination of goals and scenarios, are described in this thesis:

- *Integrated URN metamodel:* An abstract integrated URN metamodel and an implementation-oriented one are presented, based on the ITU-T draft standards for URN [24][25][26].
- *GRL catalogues:* To support reusable goal models, we present GRL catalogues, which are reusable subsets of GRL models.
- *Links between goals and scenarios:* This thesis describes user-defined links that can be created between goal and scenario elements in URN models, as well as how they can be exploited in the requirement engineering process.
- *GRL strategies:* We present a new approach to analyze GRL models using strategies, which are used for the automatic evaluation of satisfaction levels in goal models. In addition, strategies are combined with scenarios to enable integrated analysis of functional and non-functional requirements.
- *Quantitative evaluations:* We describe a new propagation and evaluation algorithm that uses quantitative values instead of qualitative values for GRL models.
- *Actor evaluations:* This thesis includes a description of a new analysis approach to evaluate the satisfaction level of stakeholders (actors).
- *Links between integrated models and external requirements in DOORS:* An import/update mechanism is presented to integrate URN models with external requirements in a commercial requirements management system, namely Telelogic DOORS [55].
- *Integrated URN tool:* Our main contribution to an integrated URN tool is the addition of a GRL editor in an Eclipse-based tool called jUCMNav [28][30], developed initially for UCM modelling. In addition, all the preceding contributions are supported in the tool and their implementation will be explained in this thesis.
- *Case studies:* This thesis uses two case studies to illustrate the usage and usefulness of the tool and of the developed approaches. In addition, they are used to validate the implementation.

1.4 Thesis Outline

This thesis is structured as follows. Chapter 2 presents background concepts related to goal-oriented modelling, the User Requirements Notation, URN-related tools, and the integration of UCM models with a requirements managements system. Then, in Chapter 3, we present the design and implementation of a GRL editor in jUCMNav. This chapter includes the description of abstract and implementation metamodels, and descriptions of the implemented editor and features such as GRL catalogues. Chapter 4 focuses on the analysis mechanisms developed for URN models. The chapter describes new evaluation algorithms, together with GRL strategies and links between GRL and UCM elements. The integration of URN models in a commercial requirements management system is presented in Chapter 5. This chapter describes the import and update mechanisms developed in both jUCMNav and Telelogic DOORS. Chapter 6 introduces a Web credit card gateway case study that takes advantage of all the modelling and analysis techniques introduced earlier. Chapter 7 discusses the benefits and impact of our contributions and then, presents our conclusions and future works.

Chapter 2 Background

This chapter provides background on goal-oriented and scenario requirements engineering techniques, with an emphasis on the User Requirements Notation (URN). An overview of common notations and tools is provided, followed by a description of current approaches combining goals and scenarios. Finally, a current technique integrating textual requirements with a scenario notation (Use Case Maps - UCM) is presented.

2.1 Goal-Oriented Requirements Engineering

In various requirement engineering (RE) frameworks and notations, goals are used increasingly as the central concept or as a supporting modelling element. In this section, two popular notations that use goals are presented. The *NFR framework* uses the notion of goal as the main focus of requirement engineering activities, whereas the *i* framework* uses goals to complete actor models describing stakeholders' concerns. The concepts in those frameworks are at the basis of the Goal-oriented Requirement Language (GRL) used in this thesis.

2.1.1 NFR Framework

The *Non-Functional Requirements framework* [13][38] (NFR framework) is a graphical notation developed to document and reason about design and knowledge. It focuses on non-functional requirements, such as security, performance, usability and cost. The abstract, fuzzy, non-measurable nature of these requirements often makes them hard to use, and reasoning about them is a major issue.

Compared with other RE approaches, the NFR framework keeps non-functional requirements as the main elements that drive the software development life-cycle, from domain analysis to system testing. It helps developers keep such requirements in mind. The benefits of this framework have been demonstrated in the modelling and analysis of

various non-functional requirements, such as security, performance and accuracy, as well as in case studies such as credit card systems [13] and office support systems [38].

Using the NFR framework, one can document, analyse and decompose requirements expressed as goals. The framework emphasizes *softgoals*, which are by definition fuzzy or ambiguous goals, in *Softgoal Interdependency Graph* (SIG) diagrams. Through these diagrams, goals are identified, decomposed and analysed. There are three types of softgoals in the framework. *NFR softgoals* represent non-functional requirements or high-level goals. Then, *operationalizing softgoals* are concrete mechanisms or solutions in the target system, such as processes, structures, constraints or representations. Finally, domain and requirement knowledge is being represented with *claim softgoals*, corresponding to argumentations.

Interdependency links connect goals in diagrams. These links correspond to contributions which are explicit (derived from a higher-level softgoal) or implicit (a side effect of a softgoal). There are two categories of links: single element contributions and multiple element contributions. The first category contributes to the destination element independently of others links. It has a type, which affects positively (*MAKE, HELP)*, negatively (*BREAK, HURT),* or is equivalent to the source (*EQUAL)*. MAKE and BREAK are sufficient contributions whereas HELP, SOME+, SOME- and HURT are not. The second type, multiple element contributions (*AND, OR)*, is a decomposition of the destination softgoal, and involves more than one source element.

Figure 1 illustrates a Softgoal Interdependency Graph for a performance softgoal (shown as a cloud). This performance softgoal has been decomposed (AND contribution) into “Space” and “Response Time”, which means that those two softgoals should be satisficed in order to obtain good performance. “Use indexing” and “Use uncompressed format” are two operationalizing softgoals, describing solutions that will affect the higher level softgoals. “Use uncompressed format” *BREAKs* (--) the space softgoal and *HELPs* (+) achieving the “Response Time” softgoal. Furthermore, “Use Indexing” *MAKEs* (++) “Response Time”.

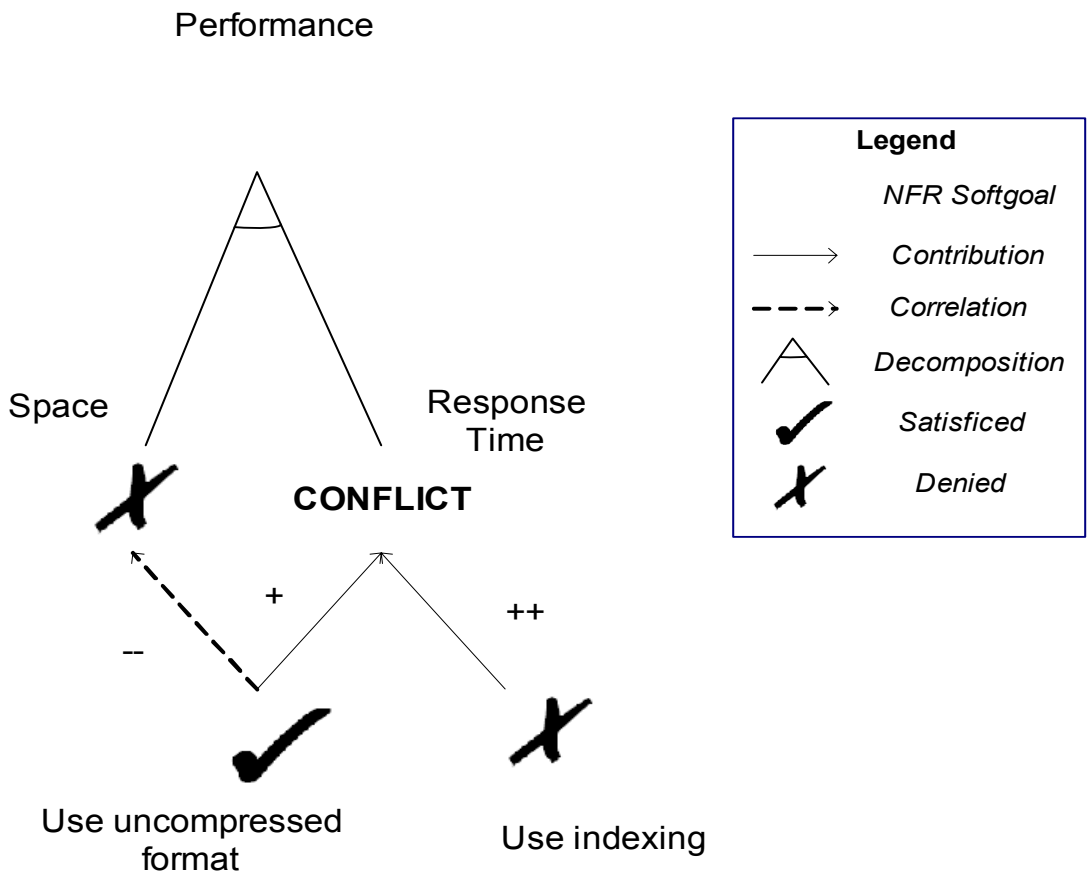


Figure 1. NFR Framework: Softgoal Interdependency Graph for Performance

An evaluation mechanism that uses these links is available in the framework. By selecting amongst alternatives and evaluating the impact of such selection, one can reason about goals and rationales. Typically, the evaluation process starts from lower-level NFR, operationalizing and claim softgoals, and propagates evaluations through the links. Using labels on the elements such as those in Figure 1, the modeller specifies a qualitative evaluation for the selected elements. Then, during the evaluation procedure, labels are added to higher level softgoals, using a qualitative evaluation scale that indicates the degree of satisfaction. The labels can have a positive satisfaction value (*SATISFICED, WEAKLY SATISFICED),* a negative satisfaction value (*DENIED, WEAKLY DENIED)* or a neutral value (*UNDECIDED, CONFLICT)*. A *SATISFICED* label (✓) corresponds to an element that is fully satisfied based on the current knowledge and understanding of the domain. However, due to the fuzzy nature of non-functional requirements, we can seldom

assume that they are fully satisfied. Further information on the domain could modify drastically the evaluation of a softgoal[1].

The labelling propagation algorithm of the NFR framework is a semi-automatic procedure, taking into consideration user inputs to assign satisfaction labels to some conflicting softgoals. First, it evaluates the impact of each contribution of the softgoals that have initial satisfaction labels on their respective destination softgoals. Multiple element contributions are evaluated as typical AND/OR graphs [39], where the source nodes' lowest satisfaction level is used for AND, and the highest satisfaction level is used for OR. Single element contributions depend on the contribution type, and are shown in — Table 1. Note that *Help* and *Some+* contributions have the same impact on parents as well as *Hurt* and *Some-*.

	Break	***Some-***	***Hurt***	***Unknown***	***Help***	***Some+***	***Make***	***Equal***
Satisficed	Denied	Weakly Denied	Weakly Denied	Undecided	Weakly Satisficed	Weakly Satisficed	Satisficed	Satisficed
Weakly Satisficed	Weakly Denied	Weakly Denied	Weakly Denied	Undecided	Weakly Satisficed	Weakly Satisficed	Weakly Satisficed	Weakly Satisficed
Undecided	Undecided	Undecided	Undecided	Undecided	Undecided	Undecided	Undecided	Undecided
Weakly Denied	Weakly Satisficed	Weakly Satisficed	Weakly Satisficed	Undecided	Weakly Denied	Weakly Denied	Weakly Denied	Weakly Denied
Denied	Weakly Satisficed	Weakly Satisficed	Weakly Satisficed	Undecided	Weakly Denied	Weakly Denied	Denied	Denied
Conflict	Conflict	Conflict	Conflict	Undecided	Conflict	Conflict	Conflict	Conflict

Table 1 NFR Framework: Impact of Single Element Contributions on the Parents

When only one element contributes to the target softgoal, or when all the contribution labels are equal, the label of the target softgoal is assigned directly. However, in more complex situations, such as when two incoming contributions have opposite impacts, the framework flags the parent node as a conflict and the user must then determine the result interactively.

In the example of Figure 1, a typical usage of the evaluation algorithm is shown. The modeller has initially specified the evaluation of the two operational softgoals, *SATISFICED* for "Use uncompressed format" and *DENIED* for "Use Indexing". Then,

[1] In this thesis, **satisficed** goals and **satisfied** goals are used interchangeably.

the labelling algorithm is applied, resulting in a *DENIED* evaluation for "Space". However, for the "Response Time" softgoal, the two opposite evaluations from the contributions (*WEAKLY SATISFICED* and *DENIED*) generate a conflict, which should be resolved by the user.

For a more detailed specification of goals, an attribute is available that specifies a level of priority of an element compared with the others. In other words, this priority attribute specifies which softgoal to focus on during the development lifecycle. During the operationalization phase of NFR models (when binding a goal model to a domain and target system), one can specify the applied operational element that is affected by a softgoal, such as a class, a class attributes, a concept or an architectural component, which are links from goals model to a functional requirements model. Other elements are available to extend the SIG in order to document and analyze knowledge about requirements. For example, it is possible to add functional requirement nodes in the diagram, and link them to design decisions.

Finally, reusability of developed goal models is realized through *catalogue* diagrams. Two types are available: the method catalogue keeps information about standard development techniques and its related decomposition methods, and the correlation catalogue keeps track of the implicit interdependencies between softgoals.

2.1.2 i* Framework

The i* framework [62][63] uses intentional agents to extend goal models with their social context. It has been developed for early phases of RE (e.g. modelling and analysis of business processes and organizations) and it focuses on analyzing decision implications from the viewpoint of each agent [63]. Agent modelling introduces a high level of abstraction for characteristics and behaviours of systems. Typical usage of this framework includes business process redesign [13], security and privacy modelling [35], information systems modelling [33] and aspect-oriented modelling [66].

Modelling is done through intentional relationships amongst agents, called *actors* in the framework. Actors have the following properties: intentionality, autonomy, sociality, contingent identity and boundaries, strategic reflectivity, and rational self-interest [62]. Any type of actor may have these properties, including systems, users, customers, or

external organizations. Actors depend on each others for satisfying *intentional elements*, which correspond to goals to be achieved, tasks to be performed, and resources to be provided [64]. Those elements are represented in the *Strategic Dependency* (SD) model, which expresses external intentional relationships between the actors, hiding the internal constructs of the actors involved.

Figure 2 shows a simple SD model with two actors represented by circles, a Customer and an Electronic Payment System, and their inter-dependencies. These dependencies are represented as links with three elements: the source actor (*depender*), which depends on the target actor (*dependee*) to satisfy an intentional element (*dependum*). In the example, Payment represents a resource to be provided by the Customer, Secure Payment is a softgoal to be achieved by the System, and Keep Password Secret is a goal to be achieved by the Customer.

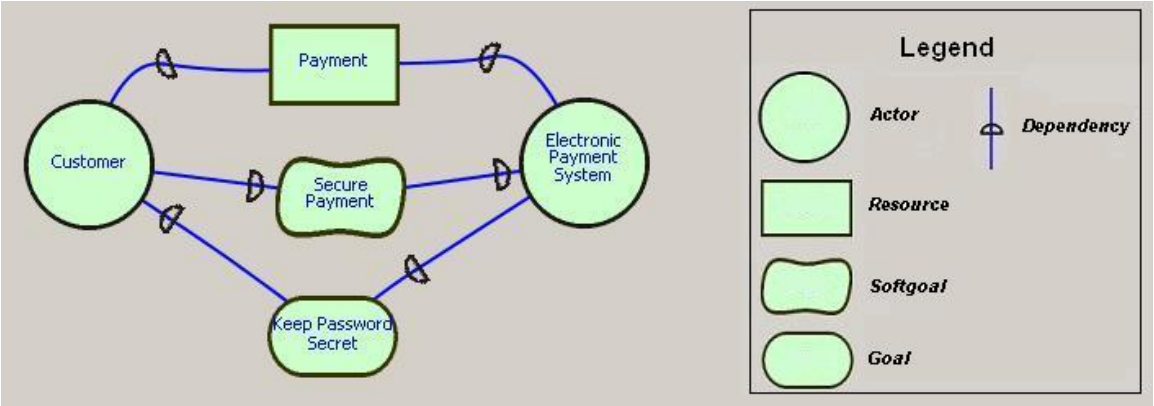


Figure 2. i* Strategic Dependency Model for an Electronic Payment System

The internal relationships inside an actor are created in the *Strategic Rationale* (SR) model. The SR model is a goal model, similar to the SIG from the NFR framework, which shows intentional elements and the links between them. Through this model, it is possible to refine the external dependencies from the SD model by specifying an intentional element as the source or destination of a dependency (instead of the actor).

The types of intentional elements available are *goals* (ellipses), which express functional requirements, *softgoals* (clouds) for non-functional concerns, *tasks* (hexagons) for elements of solutions in the domain, and *resources* (rectangles) for physical or informal entities that are available or not. Such intentional elements are connected together using intentional links, whose type can be contribution, correlation, means-end and de-

composition. Contribution links can be composed with AND or OR type. Then, a degree of impact can be assigned to the link: *MAKE* for positive and sufficient, *HELP* for positive but insufficient, *SOME+* for unknown positive, *SOME-* for unknown negative, *HURT* for negative but insufficient, *BREAK* for negative and sufficient, *UNKNOWN*, and *EQUAL*. Furthermore, *correlations* are available to express side-effects of intentional elements and use the same impact scale as regular contributions.

To complete the overview, means-end links are available to provide understanding about why an actor would engage in some tasks, pursue a goal, need a resource, or desire a softgoal [63]. Finally, task decompositions allow modellers to specify what to achieve in order to perform the decomposed task.

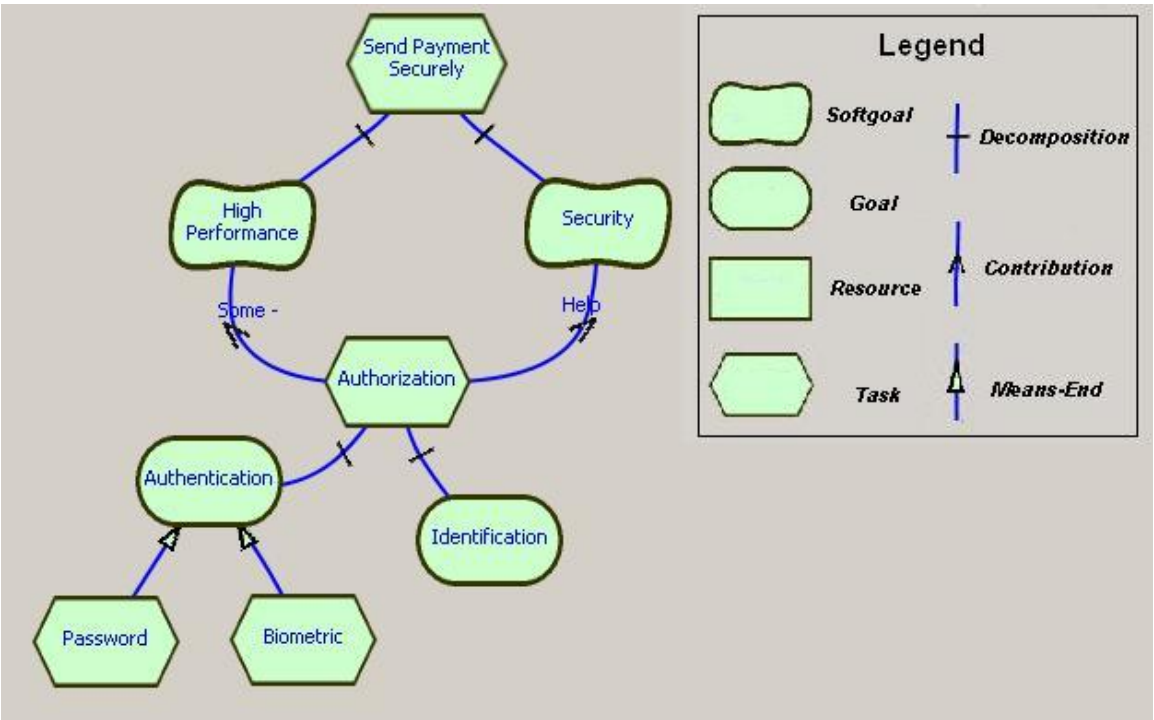


Figure 3. i* Strategic Rationale Model for an Electronic Payment System

Figure 3 shows usage of the SR model starting from the task Send Payment Securely which should be secure and should perform quickly. The authorization task affects positively the security concern and negatively the high performance concern. This task is then decomposed into Identification and Authentication. The latter uses means-end links to specify how the goal can be achieved.

2.2 User Requirement Notation (URN)

The User Requirement Notation (URN) [1][6][23] combines two complementary views, URN-NFR, the non-functional requirements notation, and URN-FR, the functional requirements notation. It supports development, description and analysis of requirements for complex, reactive and dynamic systems and is described in the ITU-T Z.150 series of recommendations [23][25][26].

2.2.1 Goal-oriented Requirement Language

The Goal-oriented Requirement Language (GRL) [1][6][25] is the notation that supports the URN-NFR view. GRL is a visual modelling notation for non-functional requirements, business goals, alternatives and rationales. Combining parts of the NFR and i* frameworks, it supports goals/agents modelling and reasoning about goal models. The notation syntax is similar to the i* framework's, using actors, intentional elements and links available in the framework (Figure 4).

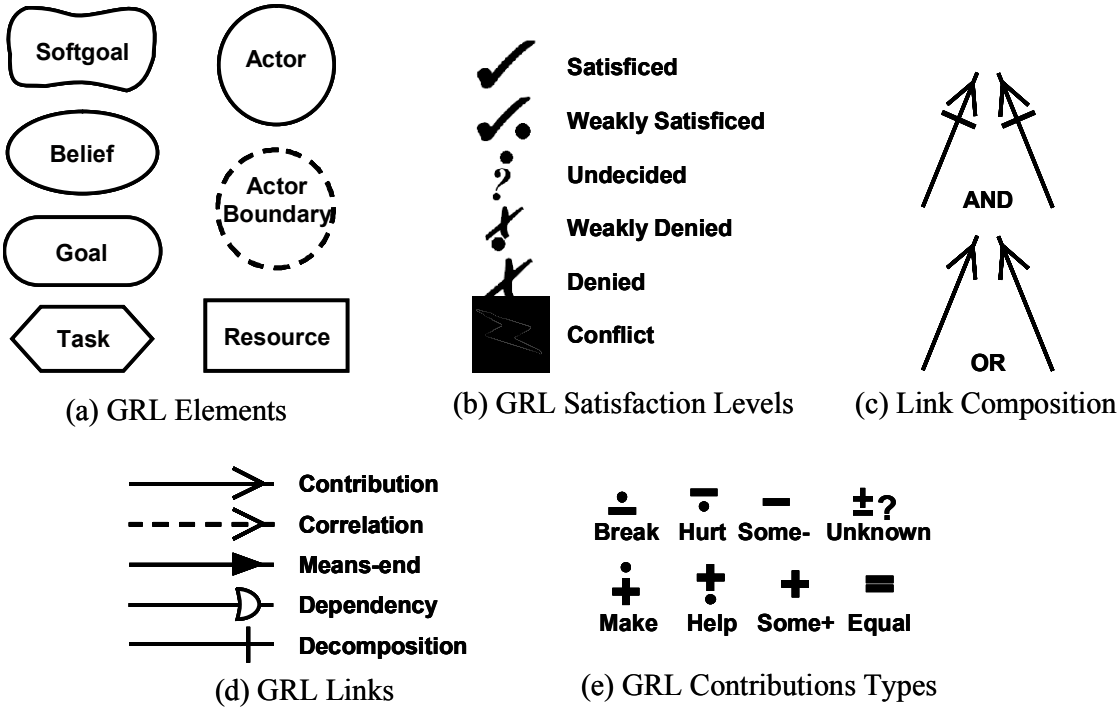


Figure 4. Summary of the GRL Concrete Notation

GRL supports an evaluation mechanism [1][6][25] similar to NFR framework. It uses qualitative labels associate to lower-level intentional elements to measure the satisfaction level of higher-level elements. The qualitative satisfaction labels associated to intentional elements goes from *SATISFICED* to *DENIED* (see Figure 4b). The propagation algorithm in the draft standard uses links created in the SR model to derive bottom-up satisfaction levels. As for the NFR framework, the algorithm is semi-automatic as it requires users to solve generated conflicts.

The GRL evaluation mechanism is applied to the electronic payment system in Figure 5. In this example, evaluation labels were first provided to elements Password, Biometric and Identification, and evaluation labels were deduced from them up to Send Payment Securely, which has a resulting *WEAKLY DENIED* evaluation.

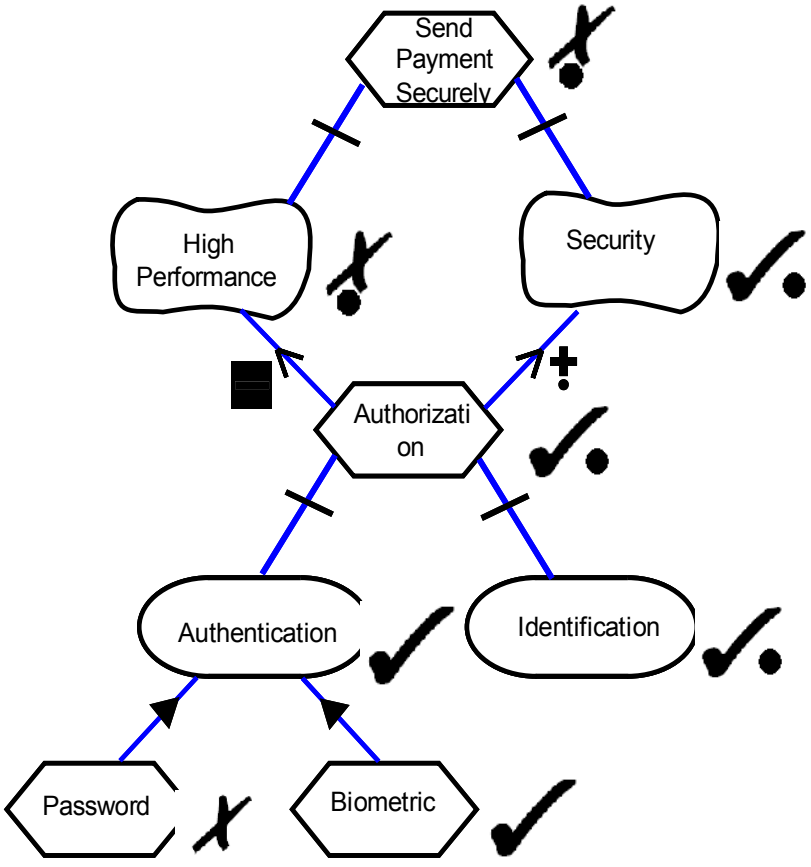


Figure 5. Evaluation of Candidate Solutions using GRL

The GRL notation supports *belief* elements, which provide justifications of the assessments in the model. Beliefs keep track of the rationales in the graphical models. It is also possible to create contributions from beliefs to GRL links or elements. During evaluation, those links modify the satisfaction levels of the linked elements/links based on the enabled beliefs.

This notation also supports *non-intentional* elements, which are elements imported from an external model. This element type does not capture the syntax or semantics of the external model, but is used for references to external elements. Non-intentional elements are defined in the GRL syntax; however, there is no specification of how to deal with them during analysis and model evolution.

The ITU-T Z.150 recommendation [23] establishes requirements for URN-NFR. GRL, as the notation for URN-NFR sub-view, meets most of those requirements. The requirements and an explanation on how GRL deals with them are listed below:

- *Expressing tentative, ill-defined and ambiguous requirements*: Using the SR model and softgoals, GRL supports abstract requirements models.
- *Clarifying, exploring, and satisficing goals and requirements*: GRL links allow refinements of goals/requirements and alternative explorations.
- *Expressing and evaluating measurable goals and NFRs*: Support for a qualitative evaluation process is available. However, there are no proposed quantitative/measurable metrics associated with the goals and NFRs.
- *Argumentation*: Argumentations are modeled with beliefs associated with corresponding elements in the model.
- *Linking high-level business goals to systems requirements*: The notation allows expressing high-level business goals and system requirements. GRL links are used to connect high-level goals to lower level system requirements. However, there is no formal way to link GRL elements to other form of requirements, such as textual requirements or scenarios.
- *Multiple stakeholders, conflict resolution and negotiation support*: SD models stakeholders and their dependencies. Through the intentional element links, requirements engineers can analyse the model in terms of stakeholder negotiation

and conflict resolution. However, there is no technique proposed in the draft standard to realize this objective.

- *General and stakeholder's requirements prioritisation*: Intentional elements support attributes for priority and criticality amongst elements. However, those attributes does not have any influence in the evaluation process.
- *Requirements creep, churn, and other evolutionary forces*: The contribution types and the GRL satisfaction levels are useful to deal with requirements evolution. These elements help the requirements engineer to evaluate the impact of new or modified requirements on other requirements.
- *Integrated treatment of functional and non-functional requirements*: GRL can deal with non-functional requirements using softgoals and with functional requirements using goals and tasks. It is also possible to express functional requirement alternatives using those elements and GRL links.
- *Multiple rounds of commitment*: Each new round of decision-making is based on previous rounds. Beliefs can help keeping information about multiple rounds of commitments. However, these requirements are not well supported because the notation as no mechanism to distinguish information coming from preceding commitment rounds, which can be supported by combining the notation with a Requirements Management System.
- *Life-cycle support*: It is supported through the refinement mechanism (GRL links).
- *Traceability*: The non-intentional elements introduced support for traceability of requirements with other notation. However, usage of this feature in the notation is not well defined in the standard.
- *Ease of use and precision*: The notation uses concepts from widely used goals/agents notation (NFR framework/i*), which helps understanding the notation.
- *Modularity*: Not supported.
- *Reusable requirements*: Not supported.

2.2.2 Use Case Map Notation

Use Case Maps (UCM) [1] [6] [26] is a scenarios-based notation for gathering functional requirements such as operational or architectural requirements. Unlike use cases or others scenarios notations such as UML 2.0 activity diagrams, UCM supports dynamic refinement at the behavioural and structural level. Furthermore, it offers an integrated view of scenarios over paths along abstract components, which allow high-level architectural reasoning. Furthermore, the dynamic syntax of the notation has proven to be useful in other domains such as performance modelling [69], test generation [7] and reverse-engineering [20].

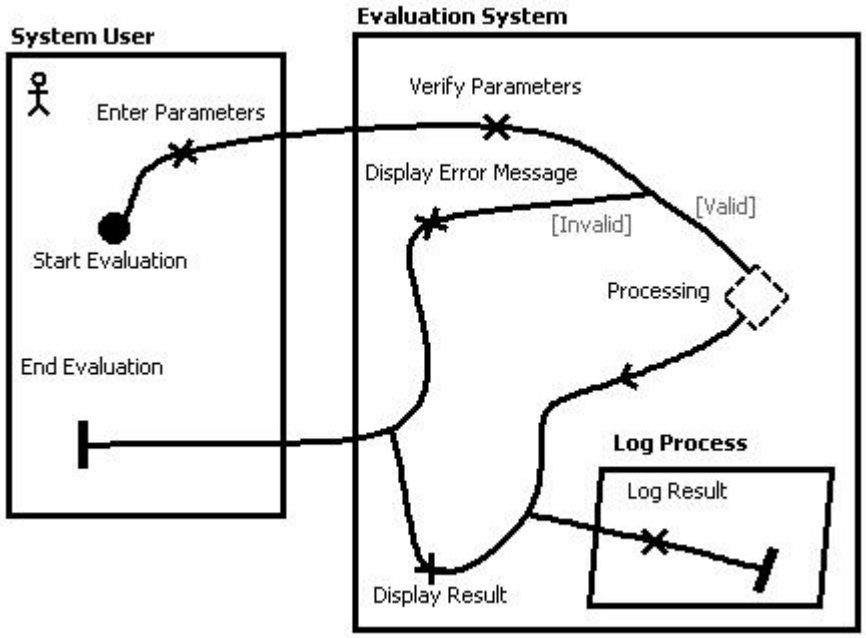
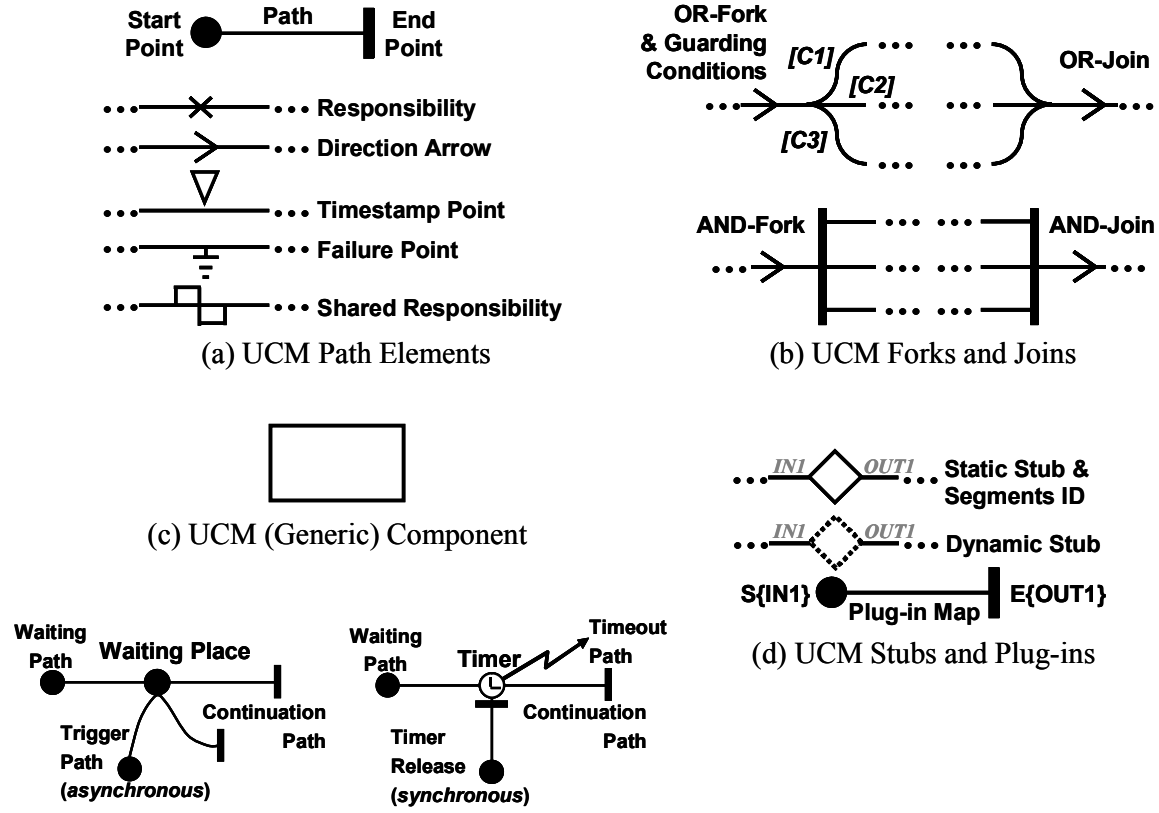


Figure 6. UCM Model of an Evaluation System

In UCM models, scenarios are sequences of *responsibilities* (X's) corresponding to activities, tasks or functions perform by a system, and disposed on *paths* (curved lines) that describe the causality flows in *maps*. Responsibilities can be bound to *components*, which are functional or logical entities. Scenarios progress through paths from *start points* (filled circle) to *end points* (bars). The above example (Figure 6) shows typical elements used in UCM model. A *stub* (diamond) is used to include sub-maps. These sub-maps, called *plug-ins*, allow the hierarchical structuring of the model and provide a way to en-

capsulate and reuse given aspects of the model. Finally, dynamic stubs are available to specify alternative maps at a given location.

The UCM syntax also includes constructs for alternative and parallel processing. AND-Forks split a path into concurrent paths while OR-Forks specify alternatives, based on the conditions for each exiting path. In addition, AND-Joins and OR-Joins are available to synchronize or merge multiple paths in the model (Figure 7).



(a) UCM Path Elements

(b) UCM Forks and Joins

(c) UCM (Generic) Component

(d) UCM Stubs and Plug-ins

(e) UCM Waiting Places and Timers

Figure 7. Summary of a Subset of the UCM Concrete Notation

UCM is a notation that attempts to fill the gap between requirements and architectural modelling [6]. To support this intent, various transformations have been developed to lower-level notations such as Message Sequence Chart (MSC) [2], UML sequence diagrams [4] and Layered Queuing Networks (LQN) [45].

2.2.3 Combining Goals and Scenarios

URN supports semi-formal modelling and analysis of requirements by combining goals and scenarios. URN combines two notations, developed in isolation, to find, manage, evolve, and document functional and non-functional requirements through the system development life-cycle. Even if GRL and UCM can be used as standalone notations, using them together allows discovering and refining requirements through goals and depicting their elaboration and realization into architectural models through scenarios. Figure 8, taken from [6], shows how URN relates to ITU-T languages and UML. However, despite a few publications where integrated URN models are used, there is no concrete definition of how best to link the two sub-views.

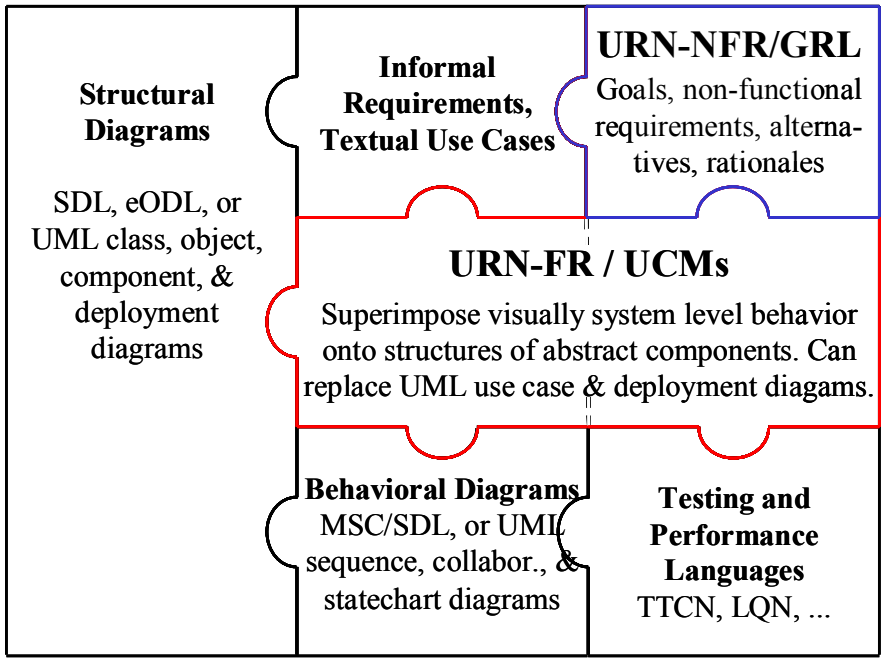


Figure 8. URN as a Missing Piece of the Modelling Puzzle

The URN syntax allows the notation to be usable to model various domains. For example, it has been used for business processes modelling [6][59]. URN can be used to model current and future business goals, their interactions, and the corresponding stakeholders with GRL. Then, business processes are modelled in UCM using identified agents in GRL as components. The dynamic constructs (e.g. OR-Forks and dynamic stubs) allow specifying alternatives and modelling current and future business processes. In this con-

text, UCM models explain what are the activities related to business goals, who is involved, where they are performed and when they should be performed [59].

Liu and Yu proposed a modelling methodology to integrate the notations [34]. They focus on answering "why" questions with goals and "what" and "how" with scenarios. Using an iterative, goal-scenario modelling process, goal refinement helps to make architectural design decisions (involving tasks) that can be ported to UCM models. Path and scenario refinements also enable the modeller to question the completeness and relevance of the goal model. This process is iterative until no more refinement can be found in the design rationales or architectural design models.

Even if the above methodology integrates GRL and UCM, no traceability links are suggested between the two views. The Z.150 standard [23] emphasizes the necessity of internal links (between GRL and UCM) and external links (to other models). External traceability links are defined as links to textual requirement documents, external requirement objects, and other models used in the development process. With those links, it is possible to perform impact analysis based on changes in one of the models, as suggested in Model-Driven Development (MDD).

Combination of goals and scenarios is an approach to requirement modelling study in other approaches. Crews-L'Ecritoire [46] proposed a methodology to guide requirements elicitation using Requirement Chunks, which are pairs of goal and scenario. It defines a bidirectional goal-scenario coupling, where the definition of one of those elements helps in the elicitation of the others. Goals and scenarios are expressed as textual elements where goals are expressed as clauses that have a verb and different parameters and where scenarios are expressed as combinations of actions. This approach helps to discover goals and scenarios in early requirements phases. However, the strict definition of requirement chunks and the necessity to link a goal to a scenario cause this approach to be valid only for functional requirements.

Another approach consist in linking NFR Framework element to UML [51][52] using a UML profile. This profile defines SIG diagram in UML, and extends UML Use Case Model to include softgoals. Then, links are created between softgoals and use cases, or between softgoals and actors. This approach is interesting to extend UML, but links do

not help defining new goals or use cases needed in early requirements. Also, the created relationships are unidirectional, from softgoal to Use Case elements.

2.3 URN-Related Tools

At the time this work was initiated, there was no tool supporting the integrated URN notation. However, there are tools for UCM models and goal models (with GRL or similar to it). This section gives an overview of these tools.

2.3.1 Goal-oriented Requirement Engineering Tools

OME/OpenOME

The *Organization Modelling Environment* (OME) [42] as well as it newer open source counterpart, OpenOME [61], support multiple goal and agent languages, including GRL, i* and NFR. OME is a Java standalone application whereas OpenOME can be integrated to multiple development environments (Eclipse, Protégé, and Visio). Figure 9 shows an i* strategic dependencies model in OME.

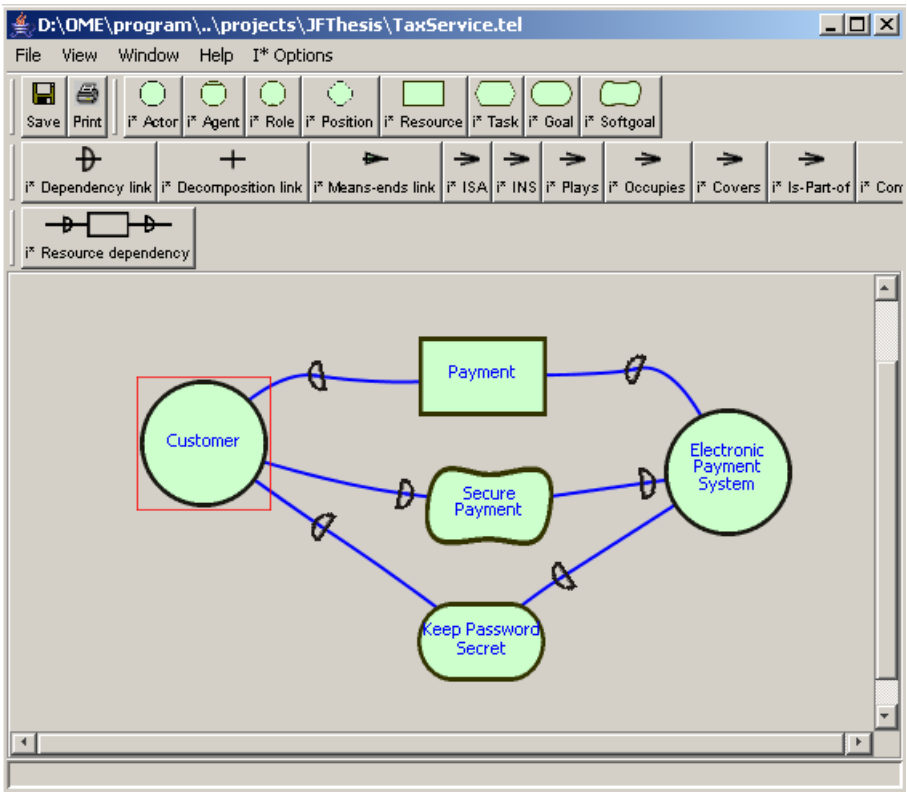


Figure 9. Strategic Dependencies Model in OME

Developed using a Model-View-Controller architecture, this tool supports notation extensions through the OME meta-framework. This meta-framework describes object types supported, such as nodes, links and expandable objects. Expandable objects are boundaries objects which support elements binding (such as i*/GRL actors).

Tool plug-ins handle model manipulations and views. The framework description is implemented using Telos files, which are set of rules that instantiate OME meta-framework elements for a specific notation. These framework descriptions are loaded by users. Moreover, the current tool architecture does not support multiple model views.

The GRL implementation supports the elements, links and evaluation algorithm presented in the preceding section. However, OME does not support embedded actors (actors inside actors), and it is not possible to create multiple GRL diagrams in the same model. Furthermore, the tool is difficult to use and has serious performance problems. Developing models with the tool is complex. Complexity increases and reliability decreases with the size of the model.

SanDriLa

SanDriLa [48] implements add-in for ITU-T languages (URN, SDL, MSC, TTCN) for Microsoft Visio. The current release (4.0) supports GRL, as shown in Figure 10. This application is a template that allows drawing GRL elements and links in a diagram. However, this allows for the drawing of syntactically incorrect diagrams and it does not include any support for model analysis.

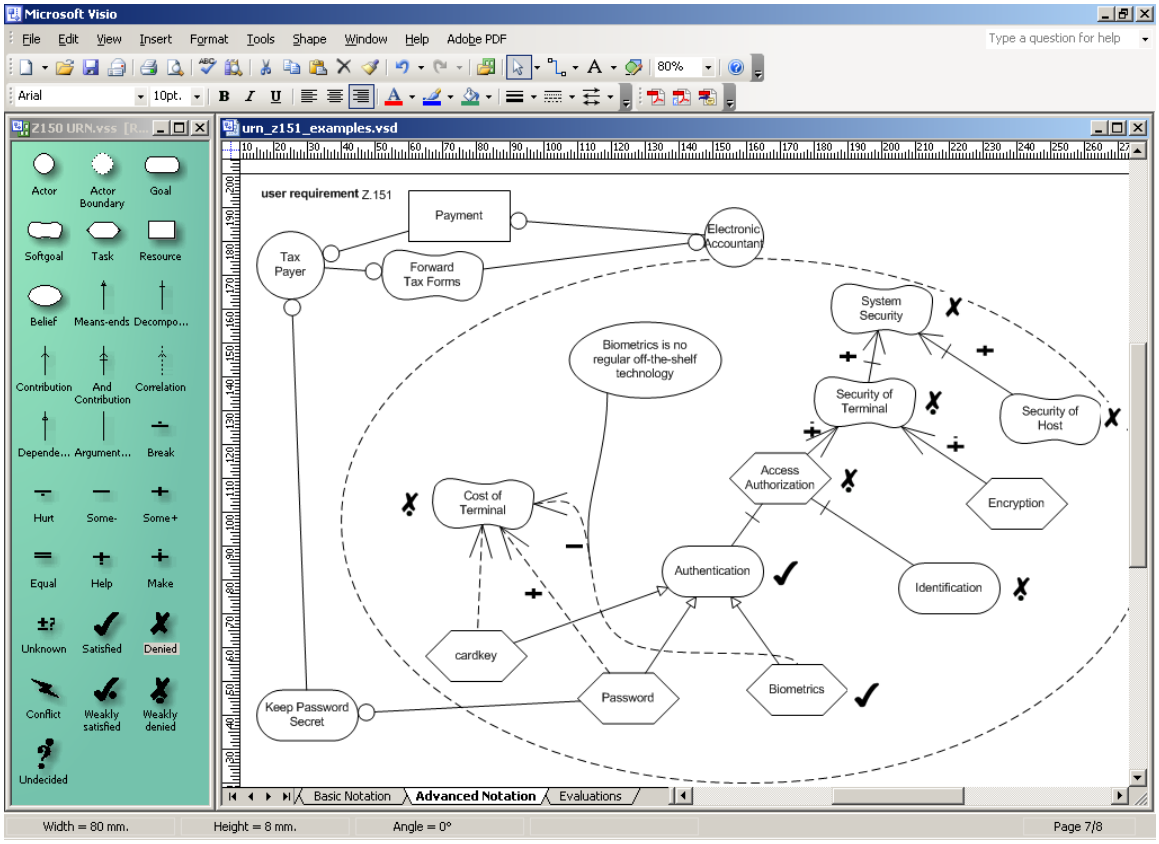


Figure 10. GRL Modelling with SanDrila for MS Visio

TAOM4E

The *Tool for Agent Oriented Modelling* (TAOM) [8] is an environment supporting TROPOS agent-oriented modelling [18][53], a formal notation extending the i* framework. It provides a model-driven methodology dealing with a development process decomposed in five phases: early requirements, late requirements, architectural design, detailed design, and implementation.

TAOM4E (Tool for Agent Oriented Modelling for the Eclipse Platform) is an open-source Eclipse plug-in distributed under the GNU Public License 2. During its development, the focus was put on the usability, flexibility and extensibility of the tool.

Strategic Dependencies and Strategic Relationships models are supported through hiding/expanding actor objects (SR model created inside actor boundaries, see Figure 11). The tool supports drag and drop from a palette or a tree view, and multiple references to the same object definition are available. Finally, models can be exported as images or as XMI (XML Metadata Interchange) files [43].

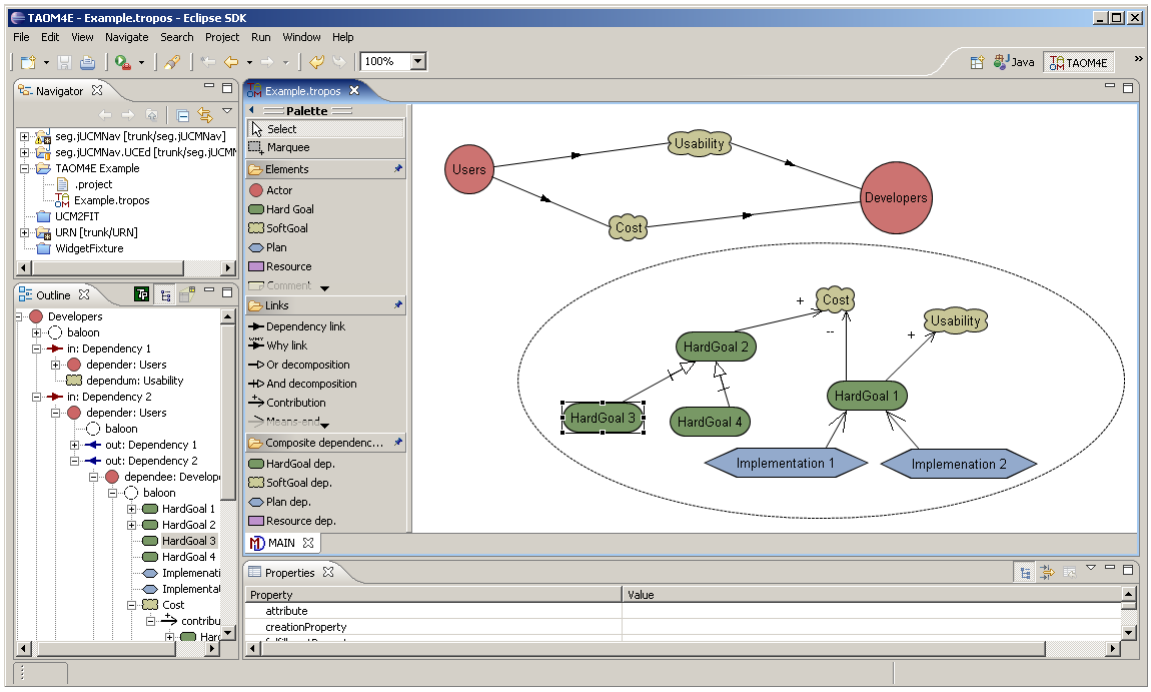


Figure 11. Goal Modelling with the TAOM4E Tool

The main limitation of TOAM4E is the absence of analysis features. The tool only provides an editor interface. However, TAOM4E supports extensions that could be use to implement analysis mechanisms.

GRTool

GRTool (Goal Reasoning Tool) [19] supports goal model editing and analysis through forward and backward reasoning algorithms [17][18][49]. Model editing is realized with three types of elements: *goals*, *top goals* and *events*. Semantically, there is no difference between *goals* and *top goals* other than distinguishing higher-level goals that should be evaluated during the analysis phase. *Events* correspond to operational elements, similar to tasks in GRL. Available links are contributions and AND/OR compositions. The contributions can take one of the two positive or negatives labels, depending on whether the contributor satisfies (or denies) partially or completely the contributee. A simple example of model developed in GRTool is shown in Figure 12.

This tool innovates with reasoning techniques that use qualitative or quantitative measures, and users can switch back and forth from one type of measure to the other. The following example illustrates how the reasoning technique is applied.

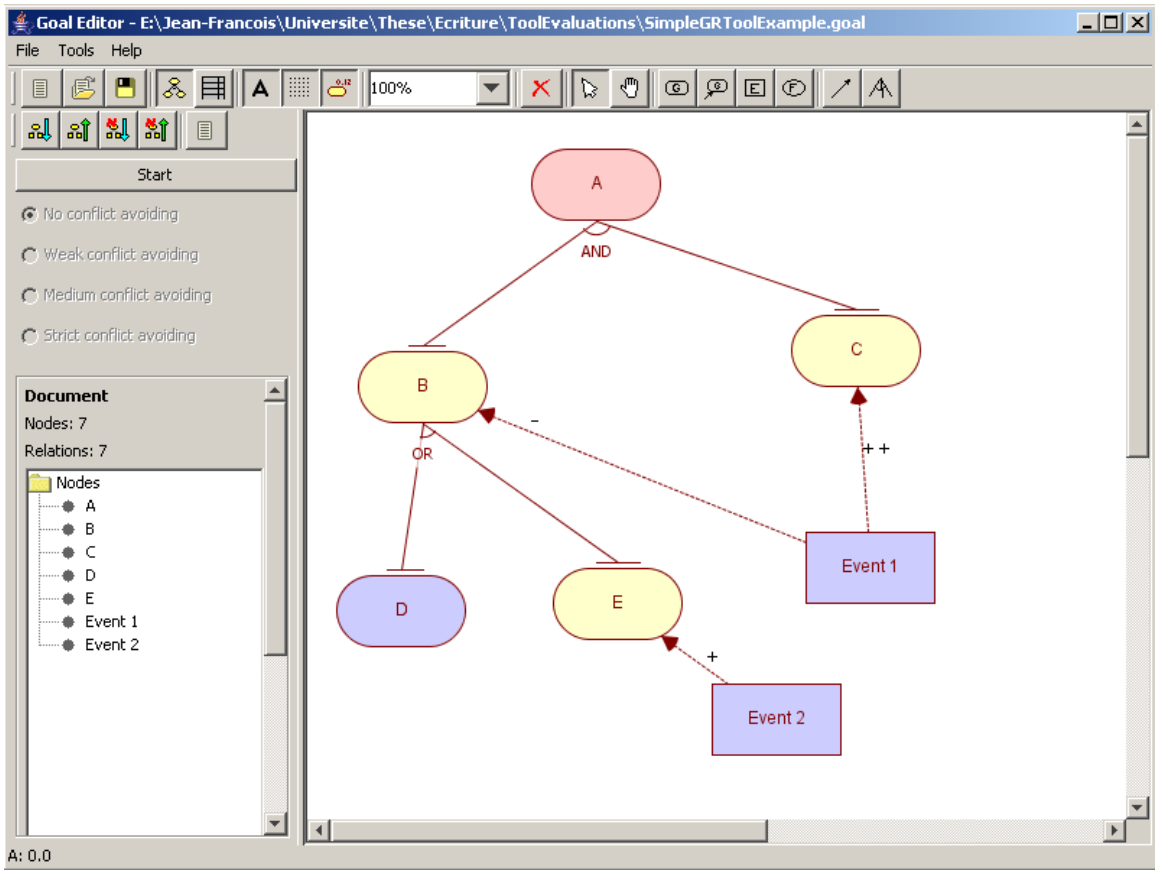


Figure 12. Goal Modelling with GRTool

Suppose a goal G. There are four possible qualitative predicates for goal G: FS(G), FD(G), PS(G) and PD(G). They correspond to full evidence that goal G is satisfied (or denied) or partial evidence that goal G is satisfied (or denied). Qualitative evaluation is made based on the rules specified in Table 2[2].

The algorithm proposed in [18] has two labels associated with each node: one for the satisfaction level and the other for denial level. Users assign an initial set of labels to nodes and propagation rules are applied based on the relations linking the various nodes. Cycles in the diagram are supported through an algorithm that stops when label updates are no longer possible (i.e., the set of current labels is equal to the previous set of labels), or when a maximum number of iterations has been executed. Node G is considered in weak conflict if its two labels are PS(G) and PD(G), FS(G) and PD(G), or PS(G) and FD(G). G is considered in strong conflict when the labels are FS(G) and FD(G).

[2] Note that propagation rules are symmetric (applicable for denied labels)

Goal – Goal Relation	*Invariant and Relation Axiom*
G:	FS(G) → PS(G) FD(G) →PD(G)
(G2,G3) **AND** G1:	(FS(G2) ∧ FS(G3)) → FS(G1) (PS(G2) ∧ PS(G3)) → PS(G1) FD(G2) → FD(G1), FD(G3) → FD(G1) PD(G2) → PD(G1), PD(G3) → PD(G1)
G2 +**s** G1:	FS(G2) → PS(G1) PS(G2) → PS(G1)
G2 -**s** G1:	FS(G2) → PD(G1) PS(G2) → PD(G1)
G2 ++**s** G1:	FS(G2) → FS(G1) PS(G2) → PS(G1)
G2 --**s** G1:	FS(G2) → FD(G1) PS(G2) → PD(G1)

Table 2 Propagation Rules for the GRTool Qualitative Reasoning Algorithm

To use quantitative values in the algorithm, qualitative labels are converted into values between 0 and 1: FS(G) and FD(G) to 1, PS(G) and PD(G) to 0.5. These values can then be fine-tuned by the users, with the definition that partially satisfied/denied corresponds to a numerical value between 0 and 1 inclusively. Furthermore, contribution labels are also converted into numerical value between 0 and 1 and can be fine-tuned by the users. Once the conversion is completed, it is possible to apply the propagation algorithm using the same rules presented before.

Finally, another algorithm is available for top-down propagation. Based on an initial set of labels for the top goals, this algorithm is applied to determine the minimal values necessary for the satisfied/denied labels of the leaf nodes in the graph.

We can observe several strengths and weaknesses of existing goal-oriented tools, as well as the lack of integration with scenario notations (as proposed in URN) and other general requirements in a RMS. Table 3 shows how these goal-oriented tools meet the URN-NFR requirements described in section 2.2.1.

URN-NFR Requirements	OME/OpenOME	GRTool	TAOM4E	SanDriLa
Expressing tentative, ill-defined and ambiguous requirements	++	--	++	++
Clarifying, exploring, and satisficing goals and requirements	++	+	++	++
Expressing and evaluating measurable goals and NFRs	+	++	--	--
Argumentation	+	--	+	--
Linking high-level business goals to systems requirements	-	--	-	--
Multiple stakeholders, conflict resolution and negotiation support	+	--	+	+
General and stakeholder's requirements prioritisation	--	+	+	--
Requirements creep, churn, and other evolutionary forces	++	++	--	--
Integrated treatment of functional and non-functional requirements	+	+	+	+
Multiple rounds of commitment	-	--	-	--
Life-cycle support	-	-	-	--
Traceability	--	--	--	--
Ease of use and precision	-	-	+	+
Modularity	--	--	--	--
Reusable Requirements	--	--	--	--

Table 3 Comparison of Goal-Oriented Tools Based on URN-NFR Requirements

2.3.2 Use Case Maps Tools

The UCM notation is supported by UCMNav (for UCM Navigator) [36][58], and recently by the newer jUCMNav (for Java UCM Navigator) [28][30]. UCMNav, in development since 1997, supports the editing and analysis of UCM models as well as transformations to others notations. The tool however presents serious usability issues, caused by a non-standard, counter-intuitive user interface. Also, UCMNav requires the presence of an X Window server, which results in difficult deployment on Microsoft Windows systems. Finally, the tool is hard to maintain because of a software architecture that has dissolved over time and because of a lack of documentation.

The more recent jUCMNav tool addresses many of these problems by providing an Eclipse-based implementation. Eclipse is a multi-platform environment, developed in Java, which supports extensions via a plug-in mechanism. This mechanism allows easy deployment, which consists in uncompressing a file in a directory, or automatically installing the plug-in through an on-line update site.

jUCMNav has been developed using two complementary plug-ins: the *Eclipse Modeling Framework* (EMF) [14] and the *Graphical Editing Framework* (GEF) [15]. EMF proposes a meta-meta model to manage models and auto-generate Java code from UML class diagrams. The jUCMNav authors developed an EMF-based metamodel for the UCM notation, which describes the abstract implementation syntax of the notation. For visualizing and editing models, GEF offers many features that facilitate the development of user interfaces compliant with the Eclipse user interface standard. Using those two frameworks together in combination with a notification mechanism, jUCMNav was developed based on the Model-View-Controller (MVC) design pattern.

jUCMNav is an open source application available under the Eclipse Public License (EPL) 1.0. The first version of the tool [28], released in July 2005, included three major views (see Figure 13): the graphical editor with a tool palette to add and manage elements in the models, the properties view to manage attributes of elements, and a graphical/hierarchical outline. Furthermore, a custom element view is available, which lists elements in the models and their descriptions. Finally, standard Eclipse views such as navigator and resource are used to manage the models like any other Eclipse-based application.

Compared with UCMNav, jUCMNav does not yet support all of the UCM constructs. The core path elements are supported, such as start points, end points, responsibilities, stubs, waiting places, timers, and forks/joins, as well as various component types, like actors, agents, processes and teams. Element and component binding to parent components is also supported. Furthermore, jUCMNav only allows the creation of syntactically valid UCM models, and verifies potential problems such as implicit loops. The tool also supports static and dynamic stubs, with plug-in bindings.

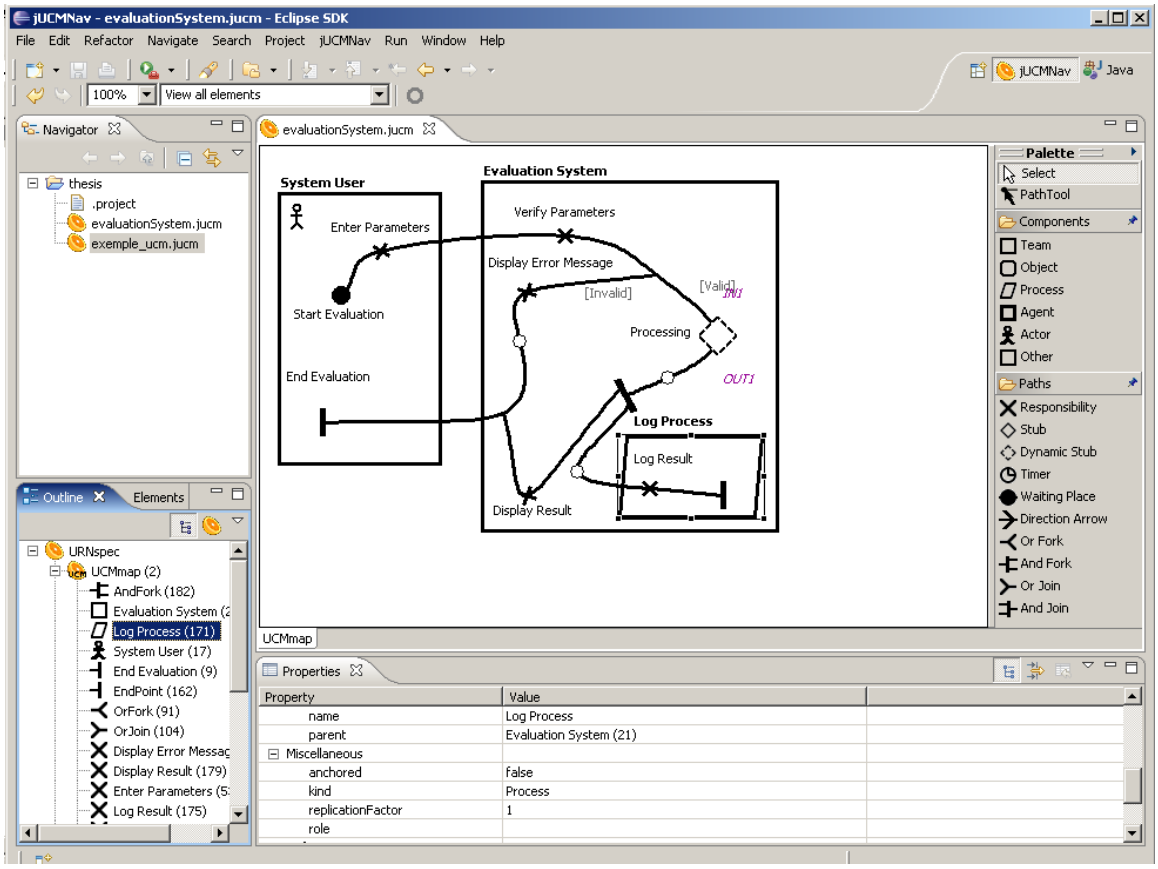


Figure 13. jUCMNav User Interface for UCM Modelling

jUCMNav offers extension points that allow the addition of other plug-ins to the tool. As suggested previously, URN models can be generated from other artefacts, which may be interesting in a round-trip requirements engineering context. A specific example is the automatic generation of UCM models from textual use cases defined in a structured natural language. Textual use cases are inherently ambiguous, and completeness and consistency are often hard to analyze. Tools already exist to extract domain models, scenarios, and finite state machines from textual use cases to facilitate this analysis, such as UCEd [50] (Use Case Editor). In [29], the usefulness of jUCMNav's extension points is demonstrated with a plug-in that generates graphical UCM models (with automatic layout) from validated UCEd project files.

At the moment, scenario definitions and a traversal mechanism have been prototyped, and transformations from UCM models to others notations have started to appear.

However, the current design has prioritized maintainability and extensibility, developer documentation is abundant, and the system's core functionality is covered by regression tests. This greatly contrasts with it precursor.

Finally, developed in parallel with jUCMNav, the ArchSynch tool [9] is an Eclipse plug-in for UCM modelling created to deal with inconsistencies between architectural documentation and implementation.

2.4 Requirements Management System

Requirements Management Systems (RMS) are software applications used to capture, manage, and analyse evolving requirements. They support functionalities such as traceability, impact analysis, and requirements change management. This section presents one of the most popular RMS, Telelogic DOORS[3], and it extension mechanism. Then, the integration of UCM models in DOORS is introduced.

2.4.1 Telelogic DOORS

Telelogic DOORS [55] is a requirements management tool that uses a client-server architecture and a revision control system to manage text objects, diagrams and document specifying requirements. In addition, it supports user-defined types of links between objects.

DOORS uses particular concepts for its structure. First, *DOORS databases* are used to store the data. The client application connects to a specific database, one at a time. Then, *folders* are used to structure the data. Finally, *projects* correspond to workspaces for requirements data. Through those concepts, users can create a hierarchical structure of folders and projects. Within a project, *formal modules* are containers of information such as textual requirements or graphics. Normally, a module is displayed as a standard document where numerical identifiers are used to distinguish objects. *Objects* are the basic unit of data. An object could be text, an image, or a heading (for an object containing other objects). Finally, characteristics about objects are stored in *attributes*. Users can define their own attributes but common attributes are also available by default.

[3] For several years, DOORS has been the RMS market leader according to reports from Gartner, META Group, Standish Group and Yphise.

Traceability is supported in DOORS through *links*. Links are relationships between source and target objects. These links are used for traceability analysis and are defined and instantiated in *link modules*. If linked source or target objects are modified, the application provides feedback by triggering *suspect links.* Those links suggest that the linked objects need inspection (modification on one end of a link may impact the other end). Once suspect links have been inspected, users should clear them. The requirements traceability analysis is driven by the *baselines*, which correspond to versions of the requirements from where to start analysis. Using baselines, it is possible to work on concurrent versions of the requirements.

DOORS supports an application-specific scripting language named DXL (DOORS eXtension Language) [56]. Many key features in DOORS were developed using DXL, such as file format importers/exporters, impact and traceability analysis, and inter-module linking tools. DXL uses a C-like syntax and allows extending and customizing DOORS. For the end users, those extensions appear as modifications to the graphical interface.

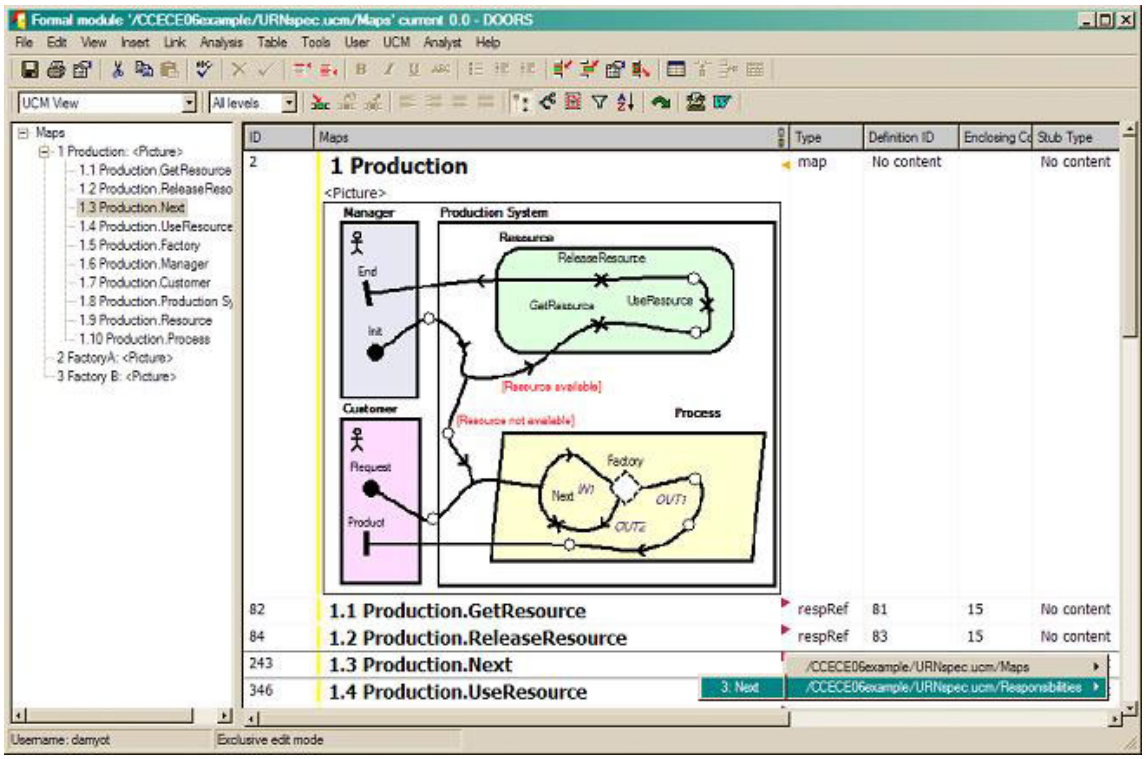


Figure 14. UCM Model in Telelogic DOORS

2.4.2 Importing UCM Models into DOORS

As suggested before, UCM models can be used to complement textual requirements. However, with the evolution of requirements over time, synchronization between UCM models and the textual requirements is difficult to maintain. An approach was developed by Jiang to support traceability between UCMs and textual requirements using DOORS [27][37].

The approach consists in using a UCM tool (UCMNav or jUCMNav) to maintain the UCM model, and import it into DOORS to keep the synchronization with textual requirements. The importing mechanism in DOORS is managed using DXL scripts, which provide an Application Programming Interface (API) for UCMs. The approach is illustrated in Figure 15.

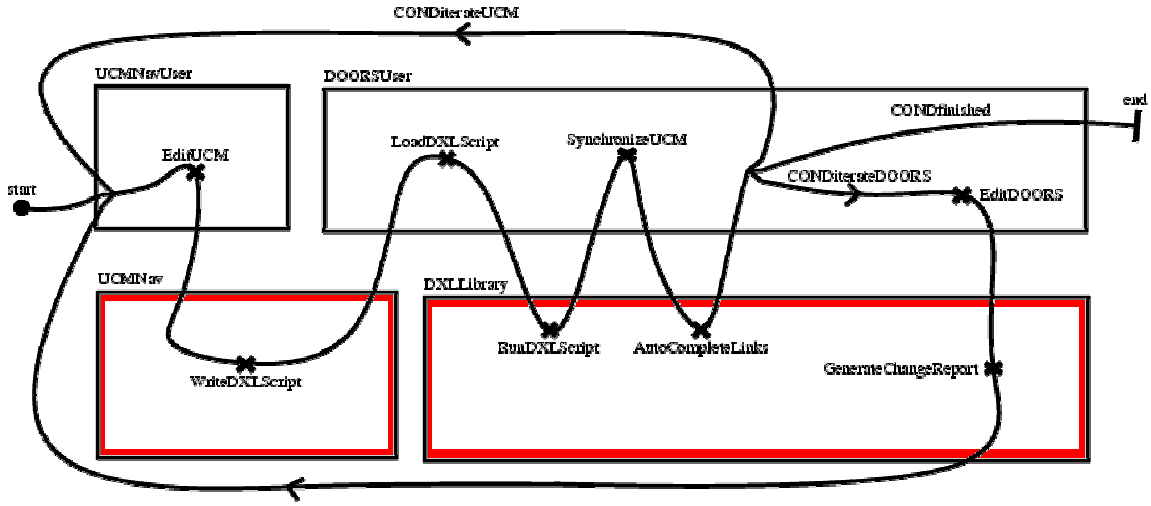


Figure 15. Integrating UCM and DOORS

The process starts by generating a DXL script from a UCM tool. The export from UCM to DXL is realized by traversing the UCM model and generating corresponding calls to the UCM DXL library. Then, the generated script is run in DOORS. Auto-completion of links is used to build the link instances between UCM elements. Once the model is imported, users link the various UCM model elements with textual requirements and modify any of the DOORS objects. A report is generated by the DXL library that flags the UCM elements that could be affected by changes to linked objects. Then, it is the responsibility of the UCM users to synchronize the UCM models with the modified textual requirements. Re-importing a new version of the UCM model may also trigger suspect links, and

customized views are provided to emphasize the places where attention is required. Synchronization can hence be achieved as the UCM model and the textual requirements evolve.

Importing a UCM model in DOORS automatically generates various formal and link modules. The formal modules are responsibilities, devices, components, maps and scenarios. Each of these modules includes their corresponding UCM elements, which are identified using unique identifiers from the UCM model. For example, the maps module contains several sections, one for each map (Figure 14). Maps are exported as images and have child elements, which are responsibility references, component references and stubs. Once each formal module has been created, the internal links are created (between UCM elements). These links defined model-based relations between elements. They could be between elements in the same formal modules, such as maps and their elements in the maps module, or between elements in two formal modules, such as responsibility references in the maps module and responsibility definitions in responsibilities module. Finally, external links are created manually, between UCM elements and DOORS objects (requirements). Those links are the main component of traceability analysis between the textual requirements and UCMs.

2.5 Chapter Summary

This chapter introduced concepts used in this thesis. First, frameworks with goals and agents as central modelling constructs have been presented in section 2.1. These frameworks were the inspiration of the Goal-oriented Requirements Language (GRL), a subview of the User Requirements Notation (URN), which was presented in section 2.2. Then, an overview of tools available for goal notations for URN's scenario notation was provided in section 2.3, followed by an existing approach supporting the integration of UCM models with textual requirements in DOORS (section 2.4).

The next chapter will explain how an integrated tool for URN can be developed.

Chapter 3 Integrated Tool Support for URN

This chapter presents a new version of jUCMNav which integrates both GRL and UCM. In section 3.1, the high-level requirements and rationales that drive the development of the tool are explained. Then, section 3.2 provides an abstract and an implementation metamodel for URN. An overview of the development and architecture of the tool and the basic editing features is presented in section 3.3, followed by GRL catalogues, a new feature supporting the reusability of GRL models (section 3.4). Finally, a case study that uses the tool is introduced.

3.1 Requirements and Rationale for an Integrated URN Tool

The main goal of this thesis consists of integrating goal and scenario modelling using URN. An integrated tool will allow editing and analyzing functional and non-functional requirements together. In addition, we want to develop a tool that will satisfy most of the URN-NFR requirements.

Our main goal of integrating goals and scenarios can be decomposed into sub-goals, as shown in Figure 16. URN models, as models used to fill the gap between requirements and architectural models, shall support analyzing the architectural impact of changes in requirements. This will be possible by linking URN and external requirements. It is considered a goal that shall be satisfied to achieve the integration of URN.

A common metamodel for GRL and UCM is also required. This goal has a positive contribution to the *Integrated Tool Support* goal, by allowing modellers to use all elements specified in URN. For this concern to be satisfied, it is required that the tool allows one to create and modify the URN model (*Editing Goal and Scenario Models* goal). In addition, the tool should be usable, should generate models that are graphically complete, and should allow the reuse of models. Finally, it is also required to have analysis mechanisms for goals and scenarios.

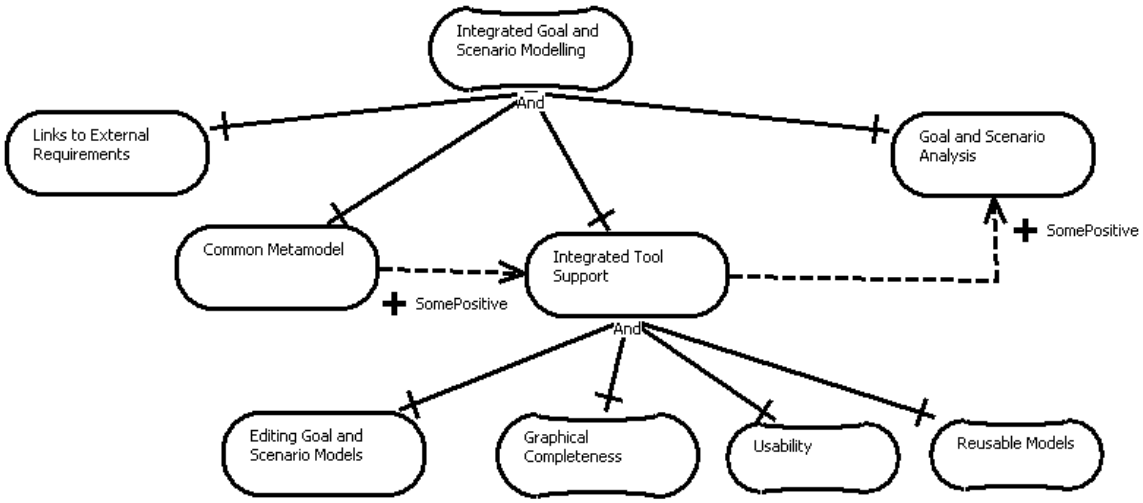


Figure 16. High-Level Goals for an Integrated URN Tool

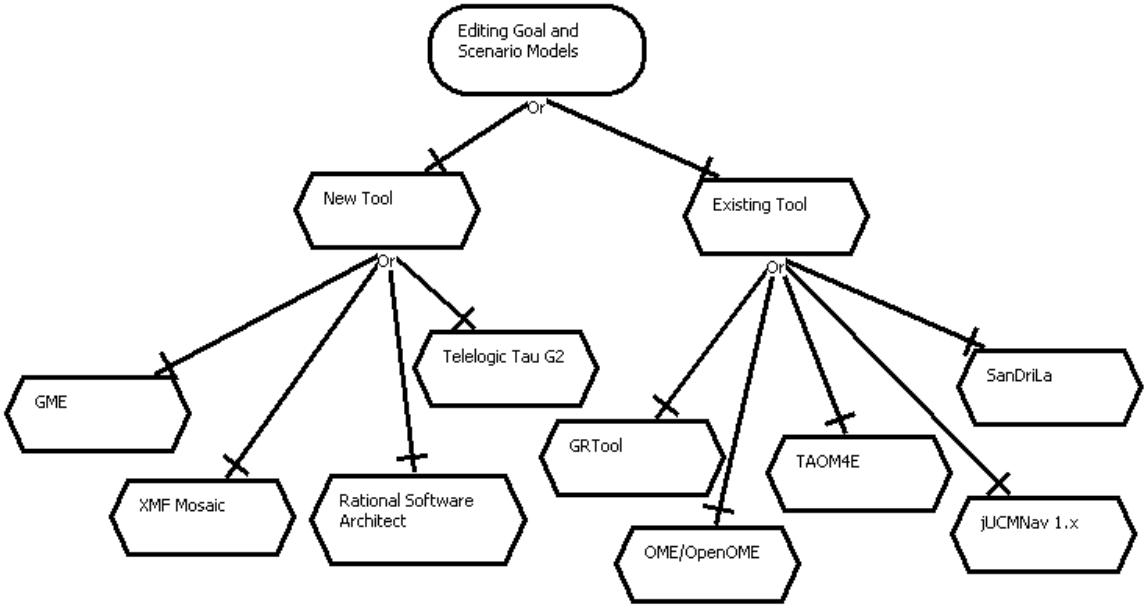


Figure 17. Implementation Solutions

As shown in Figure 17, several implementation solutions were evaluated to support an integrated URN tool. The alternatives are divided into two categories: implementing a new tool from scratch, or extending an existing tool. In [5], we evaluated the option of creating a new tool with technologies for easier and faster development of Domain-Specific Modeling Languages (DSML): Generic Modeling Environment (GME) [23], Xactium's XML Mosaic [60], Telelogic Tau G2 [54], Rational Software Architect [22]

and a combination of EMF and GEF in Eclipse. We developed editors for a subset of GRL using each technology. Then, we did an evaluation of the technologies based on criteria such as graphical completeness, editor usability, effort needed, language evolution, integration with other languages, and analysis capabilities. Our results demonstrated that for simple prototypes, GME is an interesting option to consider. However, even if Eclipse plug-ins with EMF and GEF is the solution that needs the most effort, it is the only evaluated framework with the required capabilities for developing an industrial-strength editor.

We also evaluated implementing our tool by extending URN-related tools described in chapter 2. Among the five tools evaluated, four are used to edit and analyze goals and one for scenarios. In addition, OpenOME, TAOM4E and jUCMNav are Eclipse plug-ins.

	Common Metamodel	Graphical Completeness	Usability	Reusing Developed Models	Goal and Scenario Analysis	Links with External Requirements
New Tools						
GME	Make	Some Negative	Some Negative	Some Positive	Some Positive	Hurt
XMF Mosaic	Make	Break	Hurt	Help	Help	Hurt
Rational Software Architect	Make	Break	Hurt	Some Negative	Some Negative	Help
Telelogic Tau G2	Make	Hurt	Some Negative	Some Positive	Some Positive	Help
Existing Tools						
GRTool	Break	Break	Some Negative	Unknown	Some Positive	Hurt
OME/OpenOME	Make	Break	Some Negative	Help	Some Positive	Unknown
TAOM4E	Make	Some Positive	Help	Unknown	Unknown	Unknown
SanDriLa	Break	Break	Some Negative	Hurt	Hurt	Hurt
jUCMNav 1.0	Help	Help	Help	Some Positive	Help	Help

Table 4 Contributions of the Tools on High-Level Goals

Each implementation solution contributes to the high-level goals, shown in Table 4. For goals such as *Graphical Completeness,* only two solutions have positive contributions: TAOM4E and jUCMNav. However, the only solution that contributes positively to all our requirements is jUCMNav. In addition, this is the only tool that has been designed to support URN from the start. OME supports GRL, but its implementation targets many types of goal models. In addition, there is no solution in the new tools category that could

meet the requirements. We chose to extend jUCMNav as this is the best solution for implementing an integrated URN tool in our context.

3.2 An Integrated URN Metamodel

This section presents two distinct metamodels for URN: an *abstract* metamodel and its refinement into an *implementation* metamodel. They split the core URN concepts from graphical layout information and elements/attributes which have no semantic impact. Those two URN metamodels reuse, refactor and extend the original UCM metamodel discussed in [30] to cover GRL concepts.

3.2.1 Abstract URN Metamodel

The following abstract metamodel, visualized as a UML class diagram, defines the abstract syntax of URN, independently of how diagrams are visualized. It defines what GRL and UCM diagrams are (respectively *GRLGraph* and *UCMmaps*). A URN model has one or more diagrams (GRL or UCM). To support multiple diagrams, the metamodel distinguishes *definitions* of global elements and *references* to element definitions local to diagrams. Those concepts allow having multiple references sharing the same definition.

Figure 18 defines concepts for *GRLGraph*. A graph is a composition of *GRLNode*s, *ActorRef*s and *Connection*s. First, two types of node are available in a graph: Beliefs and Intentional Elements. This metamodel supports multiple references of intentional elements through the class *IntentionalElementRef*. It contains criticality and priority attributes, which have *high*, *medium*, *low* or *none* assigned. Those attributes are defined in the references because they depend on the diagram context. Then, *IntentionalElement* is the definition class, which has a type attribute (softgoal, goal, task or resource). In addition, the type of decomposition (AND or OR) for all the references is defined as an attribute of *IntentionalElement*.

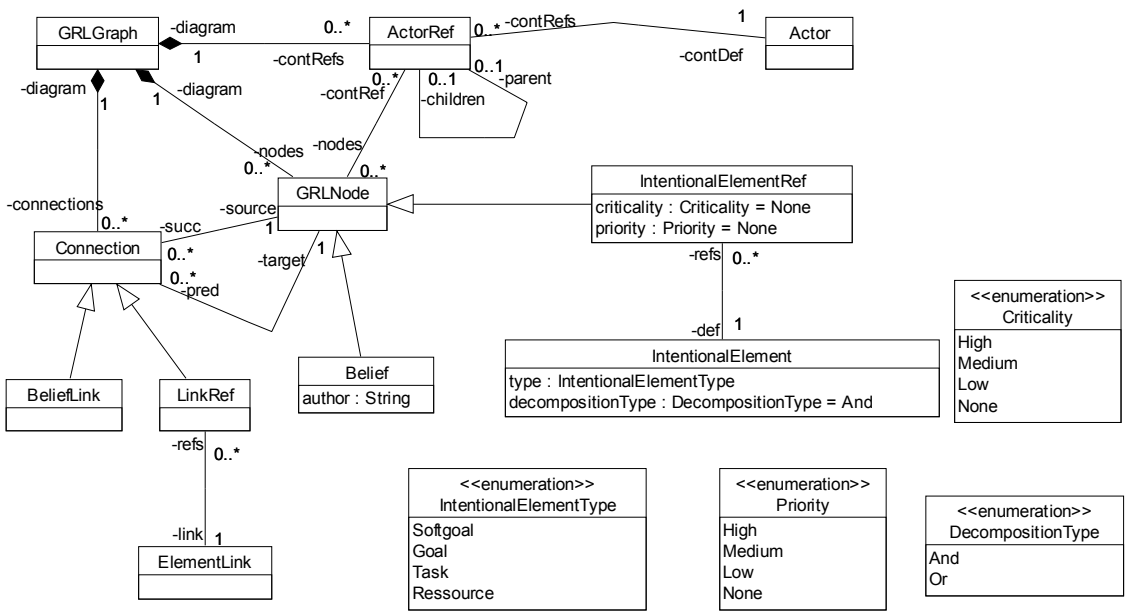


Figure 18. Main Elements of the Abstract URN/GRL Metamodel

The second node type is *Beliefs*, which are used to create rationales supporting the decision made in the diagram. Those rationales are made by authors, typically stakeholders represented as actors. An author attribute is available to trace who made the beliefs. Beliefs are defined as elements local to a diagram because they are context dependant, i.e., they are used to explain and document the diagram.

Actors are also defined with references (local to diagrams) and definitions (global to the model). *GRLGraph* are composed of *ActorRef*s, which can contain bound elements (other *ActorRef*s or *GRLNode*s).

Finally, *Connections* are the links available in diagrams. *BeliefLinks* associate *Beliefs* to other nodes, and *LinkRefs* are associations between intentional elements. Because intentional element definitions are global, links have a global definition class, *ElementLink.*

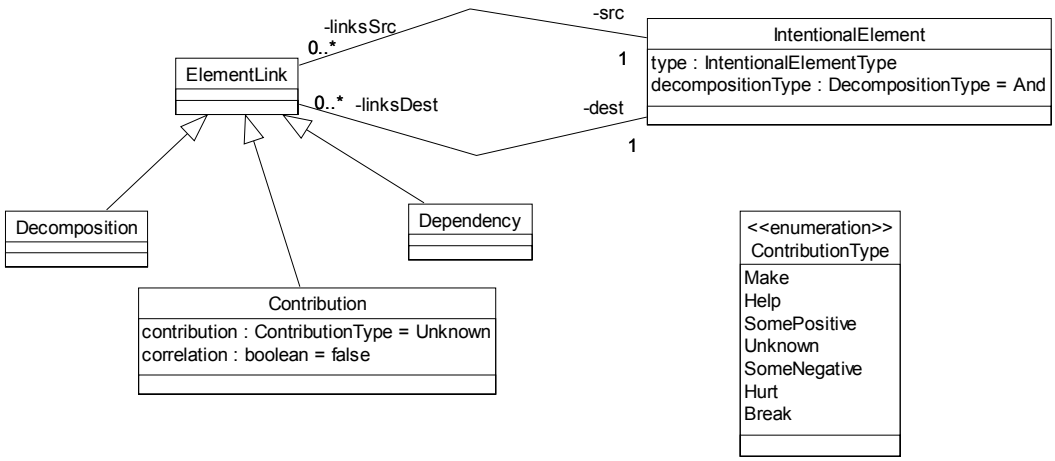


Figure 19. GRL Links Metamodel

Figure 19 shows the *ElementLinks* supported by the metamodel, whose instances of *Decomposition*, *Contribution* or *Dependency*. Each link has a source and a destination intentional element. The destination element is the intentional element that has its evaluation level affected by the link. A *Correlation* is modeled as an attribute of *Contribution* (false by default). Contribution/correlation types (*Make, Help, Some Positive, Unknown, Some Negative, Hurt* or *Break*) are defined in an enumeration (*ContributionType*).

Dependencies are also links between pairs of intentional elements. To create a typical three-element GRL dependency relationship, two links have to be instantiated: a dependency from the dependee (source) to the dependum (destination) and a second dependency from the dependum (source) to the (depender).

The implementation focuses on integrating the Strategic Rationales and Strategic Dependencies models. However, the metamodel does not support directly dependencies between actors. Instead, such dependencies are supported by binding intentional elements to actor references, and by using these two elements in the dependencies.

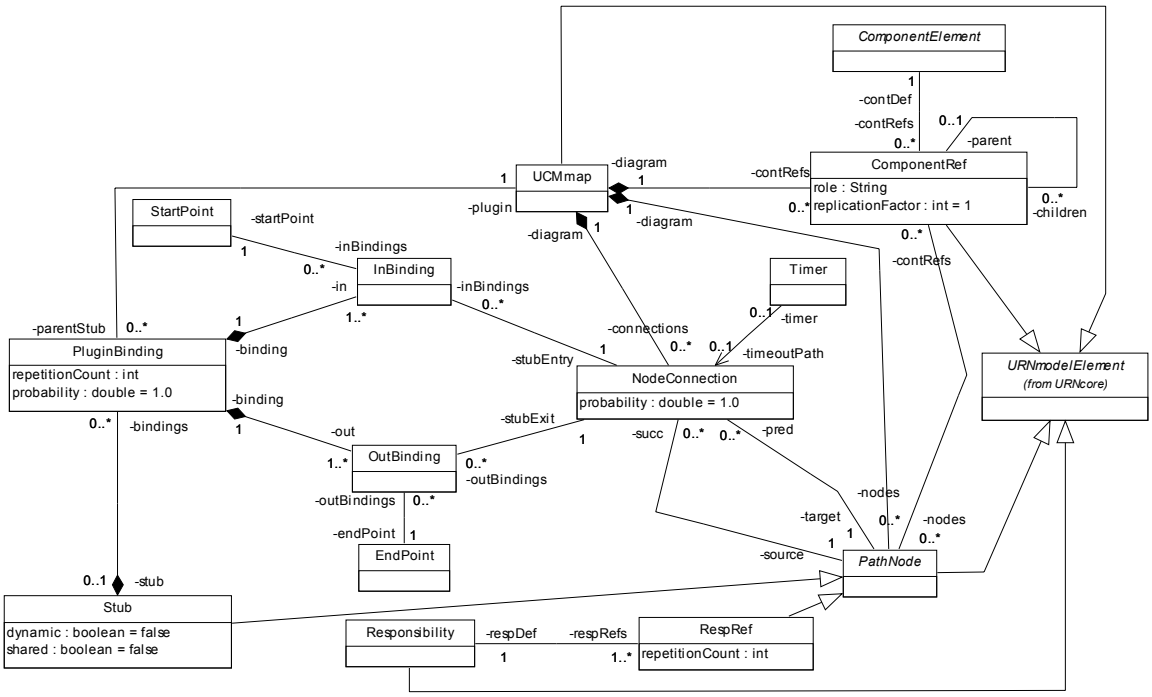


Figure 20. Main Elements of the Abstract URN/UCM Metamodel

The abstract UCM metamodel (Figure 20) defines abstract concepts available in *UCM-map*s. These maps contain component references, path nodes, and node connections. The UCM syntax supports sub-maps via the stub/plug-in binding mechanism. Others typical nodes in maps (subclasses of *PathNode*, not shown here) are start/end points, responsibility references, AND/OR forks/joins, and timers. The complete metamodel also includes classes and associations describing component and responsibility definitions, performance annotations, and scenario definitions.

3.2.2 Implementation Metamodel

From the abstract metamodel, an implementation metamodel was developed, which is used in jUCMNav. The transformation of an abstract syntax metamodel to an implementation metamodel is accomplished in two steps: refactoring the metamodel with common concepts for both sub-notation and adding visual elements to the syntax.

First, packages for both URN sub-notations (UCM and GRL) are created (Figure 21). In addition, the *URNcore* package is added to define common classes for the

complete URN model. It defines such as a generic *URNmodelElement*, a super-class of sub-notations generic classes (*GRLmodelElement* and *UCMmodelElement*). This class contains three attributes shared by all URN conceptual classes: id, name and description.

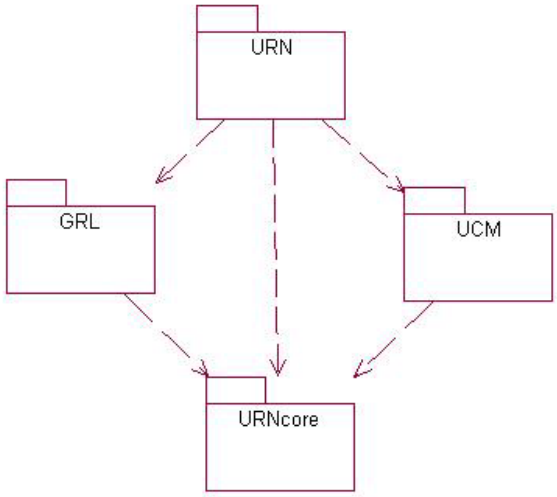


Figure 21. Main Packages in URN Metamodels

Also, amongst the most important elements in the *URNcore* package are the interfaces that define the common traits between both URN sub-languages. It includes diagrams, nodes, connections, containers, and container references (Figure 22). Diagrams are compositions of nodes, connections and container references. *ContainerRef* are elements with boundaries that support other bound elements. Using common interfaces allow developing simplified and standardized editors for both URN notations.

Then, the second step to implement the implementation metamodel consists of adding visual attributes and classes for the implementation of the implementation notation. Visual attributes are located in common interfaces defined in the *URNcore* package. Those attributes correspond to position (x, y), size (width, size) and color (line, fill). Nodes and containers also support labels, defined in *NodeLabel* and *ComponentLabel*. They are sub-classes of the *Labels* class, which have deltaX and deltaY attributes, for defining the position in diagrams.

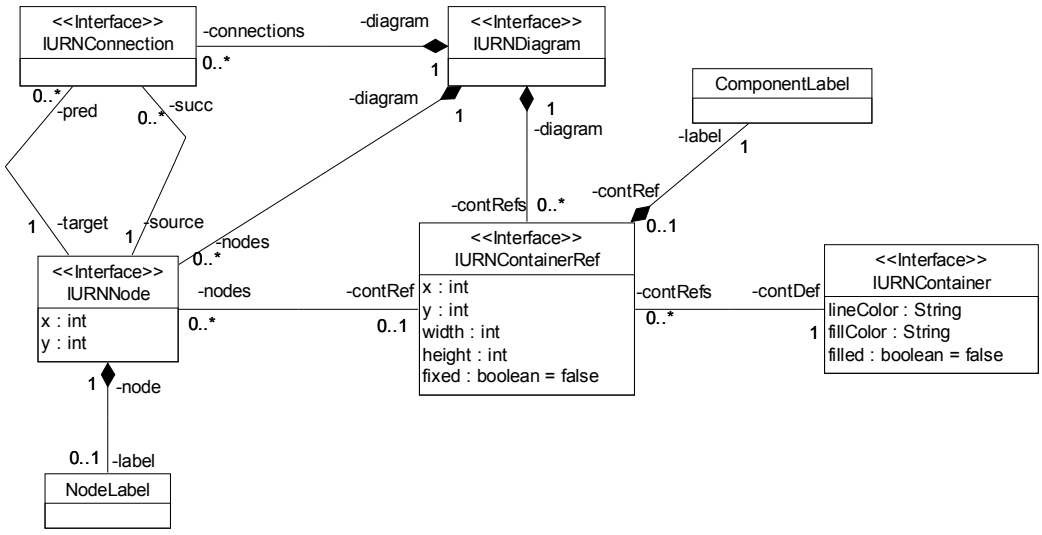


Figure 22. Common Interface for URN from *URNcore* Package

Visual elements also included link routing elements. Those elements are specific to both sub-notations and are defined in their implementation packages. In the GRL package, a *LinkRefBendpoint* class has been added to support link routing. *LinkRefBendpoints* define points relative to the visual figure by which the link should be routed. Multiple bend-points are supported, and the relative location is implemented with the x and y attributes.

Figure 23 shows how GRL conceptual classes implement the URN abstract interfaces. For instance, *Actor* implements *IURNContainer* and *ActorRef* implements *IURN-Container*. Note that all the classes, attributes, and associations from the abstract metamodel are preserved in this implementation metamodel. In addition, this package included analysis attributes and classes which will be discussed in detail in chapter 4.

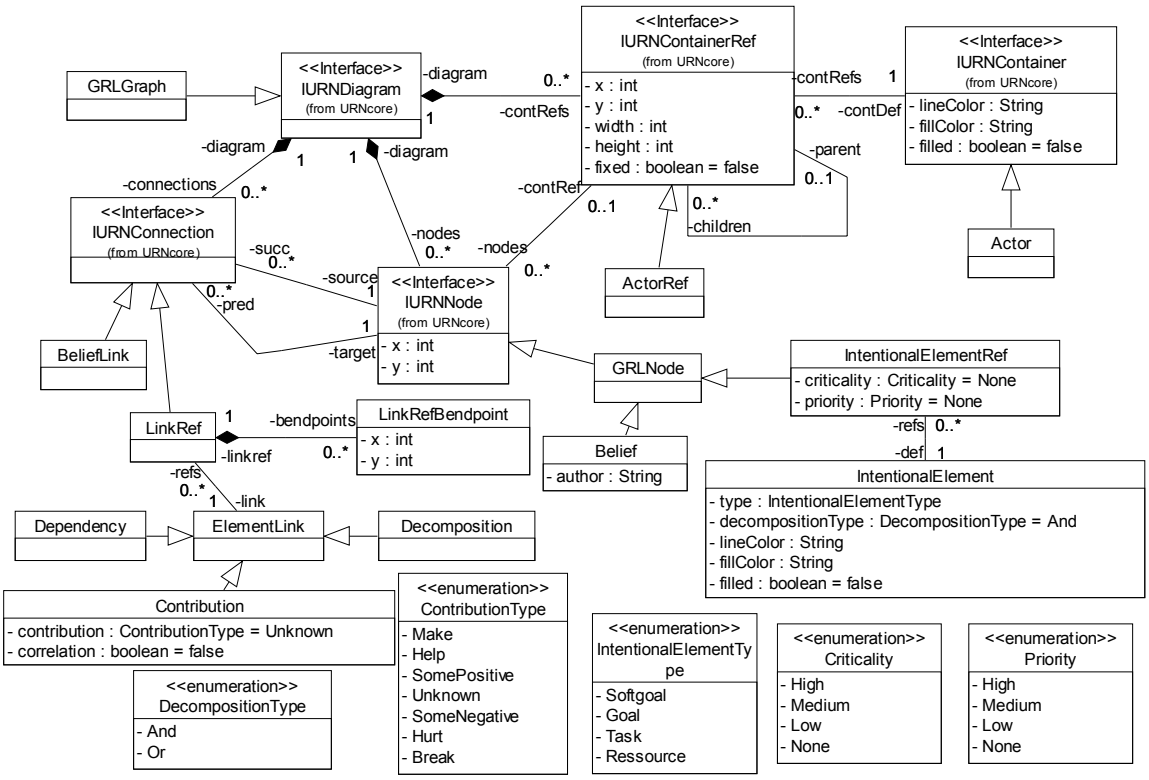


Figure 23. Main Elements of the Implementation GRL Metamodel

The UCM implementation package, shown in Figure 24, contains basic *UCMmap* elements, scenario definitions, and performance attributes associated with UCM models. A new sub-class of the *PathNode* class, *EmptyPoint*, is added to support link routing. Integration with the URN common interfaces is realized in a way similar to what was done for GRL. For instance, GRL nodes and UCM path nodes implement the *IURNNode* interface as both have a location and can be moved, connected together, and bound to a *IURNContainerRef* (i.e., an *ActorRef* in GRL and a *ComponentRef* in UCM). Most of the operations performed on the nodes, links, and components hence become common to GRL and UCM models.

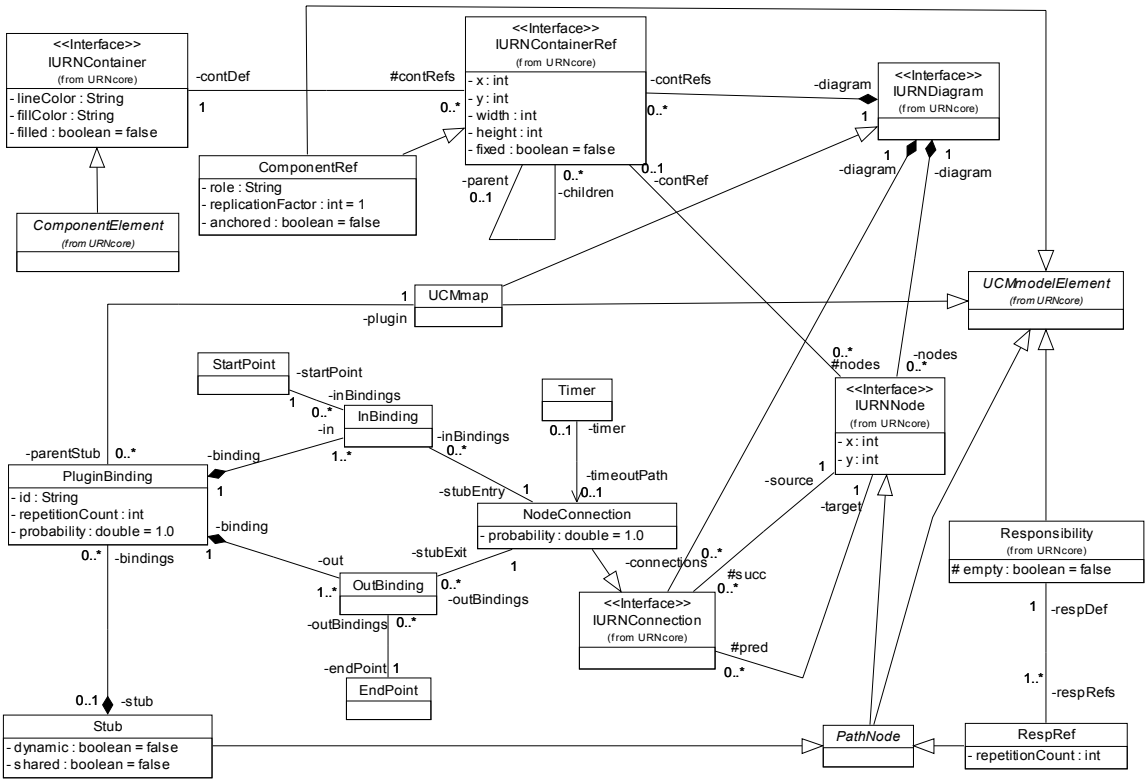


Figure 24. Main Elements of the Implementation UCM Metamodel

To complete the integration of the two notations, the top-level package *URN* (Figure 25) has been added. It includes classes defining global elements in a URNmodel (*URNdefinition*), as well as GRL and UCM diagram specifications (*GRLspec* and *UCMspec*). In addition, the *URNlink* defined in this package allows one to define links between any URN elements. Those links are discussed in detail in Chapter 4.

Finally, the two metamodels were developed to support extensions to URN and to jUCMNav. Developing new elements will only require extending the common URN interfaces. Also, adding new views to URN models (e.g., UML class diagrams) will simply require creating a new package for the view, a specification class (such as *GRLspec* and *UCMspec*) and a sub-class of *URNmodelElement*. Then, after modelling the new classes that implement URN interfaces and importing the metamodel in jUCMNav, little programming will be needed to have a new editor supporting basic functionalities.

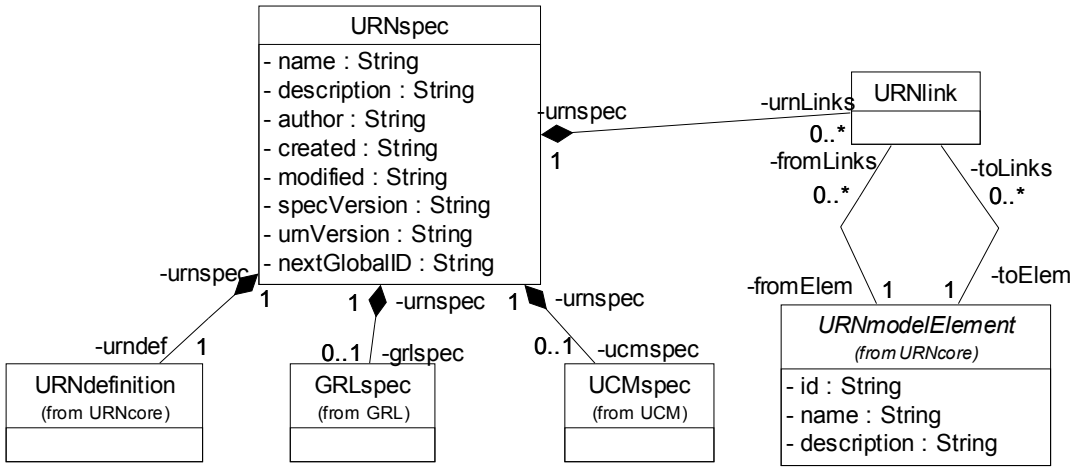


Figure 25. Element of the URN Implementation Package

3.3 jUCMNav as an Integrated URN Tool

Adding a GRL editor to jUCMNav required a major refactoring of the original code. However, maintainability and extensibility were addressed during the first development phase, which decreased the development effort. This section presents the architecture and implementation of the tool. Then, an overview of the editing features for GRL is presented.

3.3.1 Architecture and Implementation

As discussed in chapter 2, jUCMNav is a Java plug-in for Eclipse that takes advantage of EMF and GEF. It also depends on Eclipse's Standard Widget Toolkit (SWT), which is a user interface plug-in supporting multiplatform graphical user interfaces by abstracting the operating system specific libraries.

Figure 26 gives an overview of jUCMNav's architecture and dependencies, through its high-level components. The extension mechanism allows developers to implements add-ons to extend the jUCMNav features. Also, the URN models generated in the tool can be exported in various formats, such as graphics, DXL scripts or GRL catalogues (to be discussed in section 3.4).

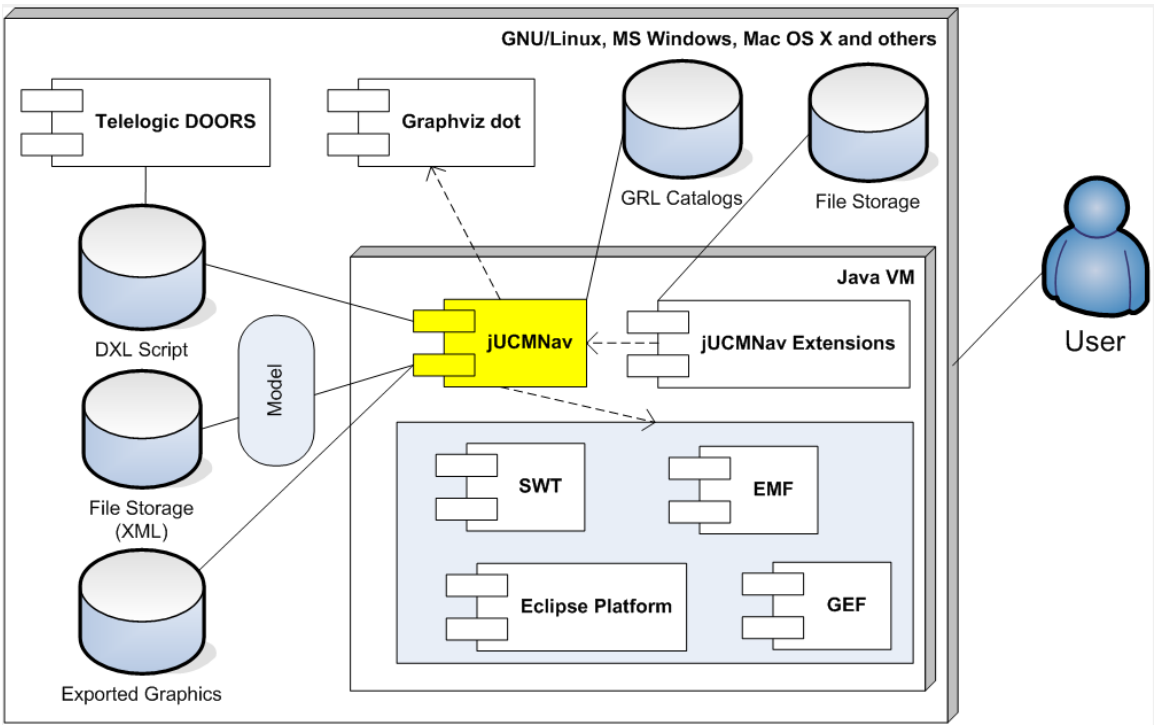


Figure 26. Overview of jUCMNav Architecture and Dependencies

From the UML implementation metamodel, EMF automatically generated nearly 100 classes. Because changes in the URN metamodel are automatically replicated in the Java implementation, the software evolution and maintenance is greatly simplified. We produced about a dozen major versions of the URN implementation metamodel, with minimal impact on the code existing at the time. Also, the framework supports model persistence via XMI serialization [43], which automates the saving/loading of models.

The Java classes generated using EMF implement *EObject,* an interface that is a sub-class of *Notifier*. This super-class is used to implement the observer design pattern [16], where external objects can register themselves as observers and receive notifications when changes occur in the observed objects. Combined with a Model-View-Controller architecture, this keeps the state of the model views synchronized with the state of the model. Hence, changes generated in a view are reflected in the other views.

The combined use of EMF with GEF imposed such architecture, which ended up facilitating the implementation of the editors. In GEF, each editable object must be associated to an EMF object. When an object is selected, a new instance of its properties is returned. These properties, defined in classes that implement the *PropertySource* inter-

face, correspond to a hierarchical list of properties associated to the model attributes or references. They are displayed in the Properties View, in control such as text boxes, selection dialogs, or drop-down boxes.

The *EditParts* are the controllers between a view and the model (model observers). They define how model instances are shown in a view. Also, *EditPolicies* define the actions that can be executed on their associated objects. Those actions, which are implemented using the Command design pattern [16], are events such as creation/deletion of objects or modifications of their attributes/references.

3.3.2 Basic Editing Features for GRL

The GRL extension is implemented using a generalization of common parts of the code, such as abstract URN editor. Because of the complexity of GRL models and their evolution over time, it is possible to develop a model over multiple diagrams, using multiple instances of the same elements. This is implemented in jUCMNav using a multi-page editor for the main view, which supports multiple URN editors (URN diagrams). The GRL editor is implemented as a sub-class of the abstract URN editor.

As shown in Figure 27, the main editor has a palette (at the right of the figure) to create the GRL elements and links. The *EditPolicies* are used to support on-the-fly feedback and prevent users from executing invalid actions. For example, a user will not be able to add links between two elements that have a link already defined. The set of *EditPolicies* is particularly useful to manage definitions and references through all the diagrams, preventing the user from creating syntactically invalid URN models. Browsing multiple diagrams in the model can be done using the tabs at the bottom of the main editor.

When a new intentional element or actor is dragged and dropped from the palette to the editor, two elements are created: a reference in the diagram and a definition in the model. Using the properties view, one can modify the definition of an element in the diagram. The hierarchical outline view contains all the references in diagrams as well as the definitions in the model. From this view, it is possible to drag and drop a definition in a diagram, which automatically creates a new reference in the corresponding diagram. To delete an element using the outline view, all it references must have been deleted first.

Definitions are not deleted automatically when all their references are deleted because modellers may want to reference it later in the model. However, this behaviour can lead to a model with many unreferenced definitions. In the outline, unreferenced definitions are displayed in gray to identify them easily.

A similar implementation is available for links. Using the palette to build links creates a reference between the two intentional elements in the editor. In addition, the link definitions are available under each of the intentional element definition, in the outline. For model readability, a new link between 2 elements does not create links between each of their references. It is the modeller's responsibility to add these references in the views. However, dragging and dropping elements from the outline to diagrams adds by default all the link references (to other elements also available in the diagram). Deleting the latest reference to a link also delete its definition. This behaviour is implemented because unreferenced links would have been hard to manage for modellers. Such unreferenced links would also have an impact on model analysis, which could cause misleading results.

Beliefs are implemented as comments in jUCMNav. They are use to keep rationales provided by the stakeholders or modellers. In the draft standard, the belief links can modify the evaluation level of an intentional element or an association. This feature can be confusing since belief evaluations modify the model results.

In our editor, belief links are associated to intentional elements affected by beliefs, but they do not affect the evaluation level. We have implemented new analysis mechanisms to support multiple evaluations (chapter 4), which we consider easier to use than belief evaluations. In addition, beliefs are local to GRL diagrams. The *author* attribute of a belief is set by default to the operating system username, which simplifies the tracking of comments from multiple modellers.

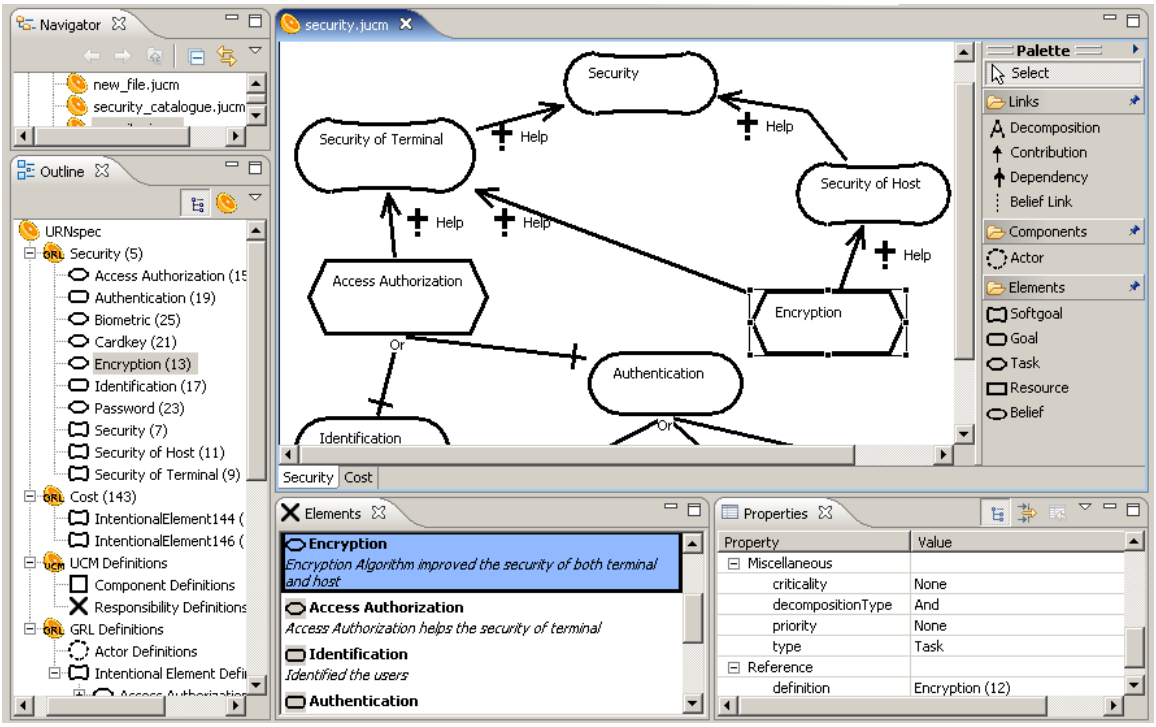


Figure 27. GRL Editor in jUCMNav

Intentional elements use an automatic resizing algorithm in order to minimize the image size based on the name of the elements. When an element is larger than the default size, it uses multiple lines to display its name if this can reduce the element width. Another mechanism used to improve the readability of diagrams is the possibility of adding bend-points to links, to indicate routing. Bendpoints allow modellers to control how links are displayed.

As for its UCM counterpart, the *Element View* is available to display the names and descriptions of the GRL intentional elements referenced in the current diagram. Finally, *contributions* are shown using the icon labels and the name. The possibility of having the contribution icons and names can facilitate the understanding of the diagrams by new users of the notation.

Finally, an optional auto-layout mechanism, previously available for UCM, is implemented for GRL. It relies on Graphviz [40] to position diagram elements. This feature is necessary to support the automatic generation of diagrams, which is required particularly in the context of reverse/round-trip requirements engineering. It is also required to develop usable GRL catalogues, which are explored in the next section.

3.4 Goals Catalogues

Supporting reusable models is a requirement for GRL. However, there are no usable mechanisms in other tools to do so. jUCMNav supports GRL catalogues, which are reusable artefacts that can be imported in a URN model. This feature enables the development of reusable high-level models for particular non-functional requirements by abstracting the specific usage context.

3.4.1 Catalogue Design and Implementation

GRL catalogues are repositories of reusable GRL models, or patterns, often used to describe common model elements and relationships related to non-functional aspects. Modellers can reuse the catalogues to start new models or add concerns to existing ones. A catalogue has a name, a description, an author, and a list of intentional elements, followed by a list of their links. *Actors* are excluded from the catalogues because they are mostly domain specific.

Catalogues are described as standalone XML files. The main advantage of implementing catalogues in external files is that they not depend on jUCMNav. Other tools can use them in the future, or they can be produced by other tools as well. Also, in jUCMNav, they are implemented using the import/export mechanism provided by Eclipse. Thus, they are created from standard URN models, and do not require the development of a new editor. However, modifications to catalogues must be done through importing and exporting them. In addition, once a catalogue is created, the model used to create the catalogue and the derived catalogues may evolve in parallel.

Eclipse supports importers/exporters using extension points, which are interfaces to extend plug-in functionalities. Other features that currently use extension points include the image exporter and the UCEd importer (discussed in chapter 2). In jUCMNav, import/export extensions are supported using classes that implements the *IURNImport*/*IURNExport* interfaces.

To export a URN model, *URNspec*, a high-level object for URN model, is used by the exporter. It enables traversing the list of intentional element definitions and inserting them in the XML file with their exported attributes (id, name, description, element type and decomposition type). Then, *contributions* and *decomposition* are exported, using ref-

erences to intentional element identifiers for the source and destination elements. In addition, contributions are exported with the contribution type and correlation attributes. For further information on the GRL catalogues representation, an XML schema is available in Appendix A. Note that current exporter uses the complete URN model to export a catalogue. However, generating a catalogue for a specific GRL diagram (based on the references) could be implemented easily but is left for future work.

Once a catalogue is created, modellers use the jUCMNav importer to import it in other URN models. By parsing the XML file, intentional elements and link definitions are created. Using the auto-layout mechanism, a new GRL diagram is generated that included all the elements and associations from the GRL catalogues. Then, one can use these elements and links in their models to add domain-specific actors and dependencies.

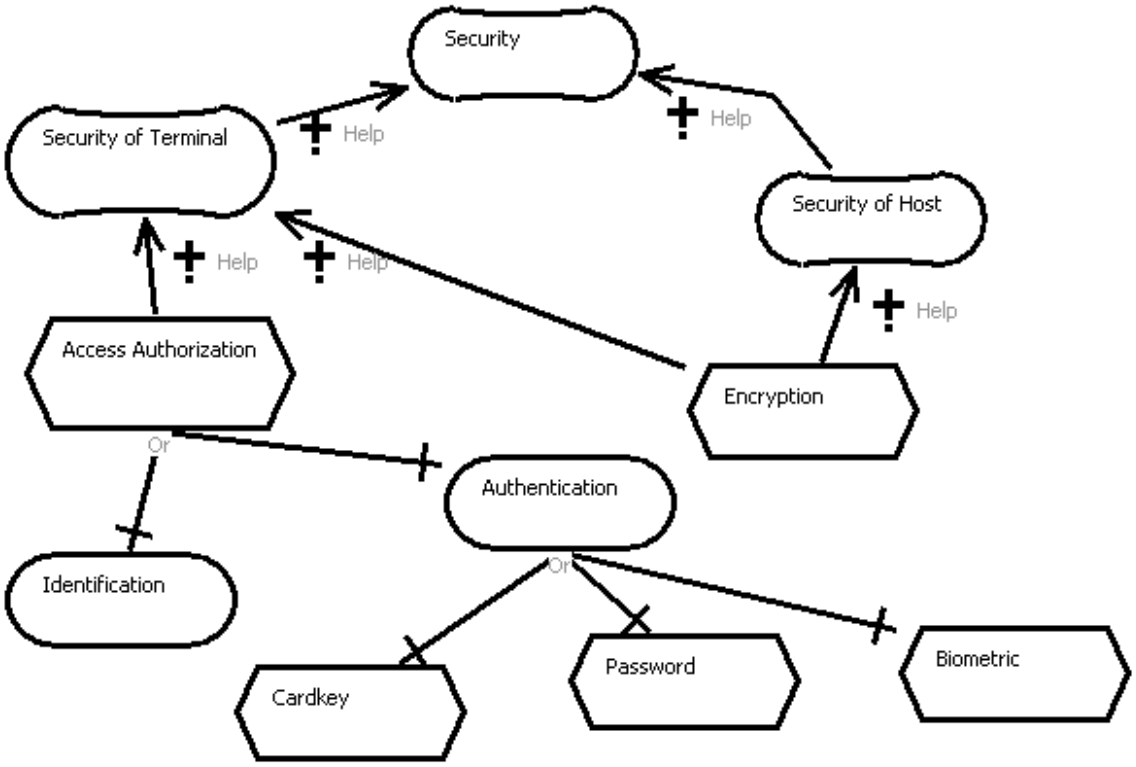
3.4.2 Example of a Security Catalogue

Catalogues are useful to represent and reuse high-level models for non-functional requirement models such as security models [13]. In this section, a catalogue that models security for client-server applications is developed. The GRL model representing the catalogue is shown in Figure 28.

In the context of client-server applications, security must be available in the terminal and in the host. Those two softgoals help achieving security, but do not guarantee it, which explains why the links are modeled as contributions. Then, the catalogue includes two sample concrete solutions for security (tasks): access authorization and encryption. These two tasks help satisfy the security of the terminal and the security of the host.

Access authorization is composed of two goals, identification and authentication. They are modeled with an OR decomposition, which indicates that only one element in this decomposition needs to be satisfied in order to satisfy the destination (access authorization). Three typical alternative solutions are available to support authentication: cardkey, password or biometric.

The XML file generated by the exporter from this URN model is also shown in Figure 28.




```
<?xml version='1.0' encoding='ISO-8859-1'?>
<grl-catalog catalog-name="security" description="Security Catalogue" author="Jean-François Roy">
 <element-def>
  <intentional-element id="6" name="Security" description="" type="Softgoal" decompositiontype="And"/>
  <intentional-element id="8" name="Security of Terminal" description="" type="Softgoal" decompositiontype="And"/>
  <intentional-element id="10" name="Security of Host" description="" type="Softgoal" decompositiontype="And"/>
  <intentional-element id="12" name="Encryption" description="" type="Softgoal" decompositiontype="And"/>
  <intentional-element id="14" name="Access Authorization" description="" type="Softgoal" decompositiontype="Or"/>
  <intentional-element id="16" name="Identification" description="" type="Softgoal" decompositiontype="And"/>
  <intentional-element id="18" name="Authentication" description="" type="Softgoal" decompositiontype="Or"/>
  <intentional-element id="20" name="Cardkey" description="" type="Softgoal" decompositiontype="And"/>
  <intentional-element id="22" name="Password" description="" type="Softgoal" decompositiontype="And"/>
  <intentional-element id="24" name="Biometric" description="" type="Softgoal" decompositiontype="And"/>
 </element-def>
 <link-def>
  <contribution name="Contribution" description="" srcid="8" destid="6" contributiontype="Help" correlation="false"/>
  <contribution name="Contribution" description="" srcid="10" destid="6" contributiontype="Help" correlation="false"/>
  <contribution name="Contribution" description="" srcid="14" destid="8" contributiontype="Help" correlation="false"/>
  <decomposition name="Decomposition" description="" srcid="18" destid="14"/>
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  <decomposition name="Decomposition" description="" srcid="24" destid="18"/>
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  <contribution name="Contribution" description="" srcid="12" destid="10" contributiontype="Help" correlation="false"/>
</link-def>
</grl-catalog>
```

Figure 28. GRL Security Catalogue

3.5 Model Creation Example: a Client-Server Application

This section presents a simple case study that uses jUCMNav to develop a URN model. The context is the following. Since security has become important for an organization that develops Web-based applications, this organization is considering improving how to access it applications securely. A URN model is used to evaluate the impact of different solutions on other non-functional requirements. The corresponding high-level architectures are also developed. For this model, the security catalogue from the preceding section is reused.

First, a high-level domain-specific model is created. There are three actors for the Web-based applications, which corresponded to the stakeholders of the systems (Management, Shareholders, and Users). Those stakeholders have different concerns. The management of the organization is concerned with the project's cost, modeled as a goal. Then, shareholders are concerned with getting the maximum return on their investment. Finally, the system users want an application that is easy to use. This concern corresponds to a non-functional requirement, or *softgoal* in GRL. Those intentional elements are bound to their corresponding actors (as shown in Figure 29).

The next step is the modelling of relationships between intentional elements. There is a relation between minimum cost and return on investment, where minimizing the cost helps getting a higher return on investment. This is modeled using a *Help* contribution. Then, to achieve a higher return on investment, users should use the developed system. However, having them use systems implies addressing their main concern, which is system usability in this example. A new softgoal corresponding to system usage is added to the model and has a *Help* contribution from the usability softgoal. Furthermore, a two-element dependency is used to represent that return on investment depends on the system usage. Finally, it is assumed that users need training, modelled here with a task, in order to adopt a system. This task improves system usage, but makes a negative contribution to the cost of the system.

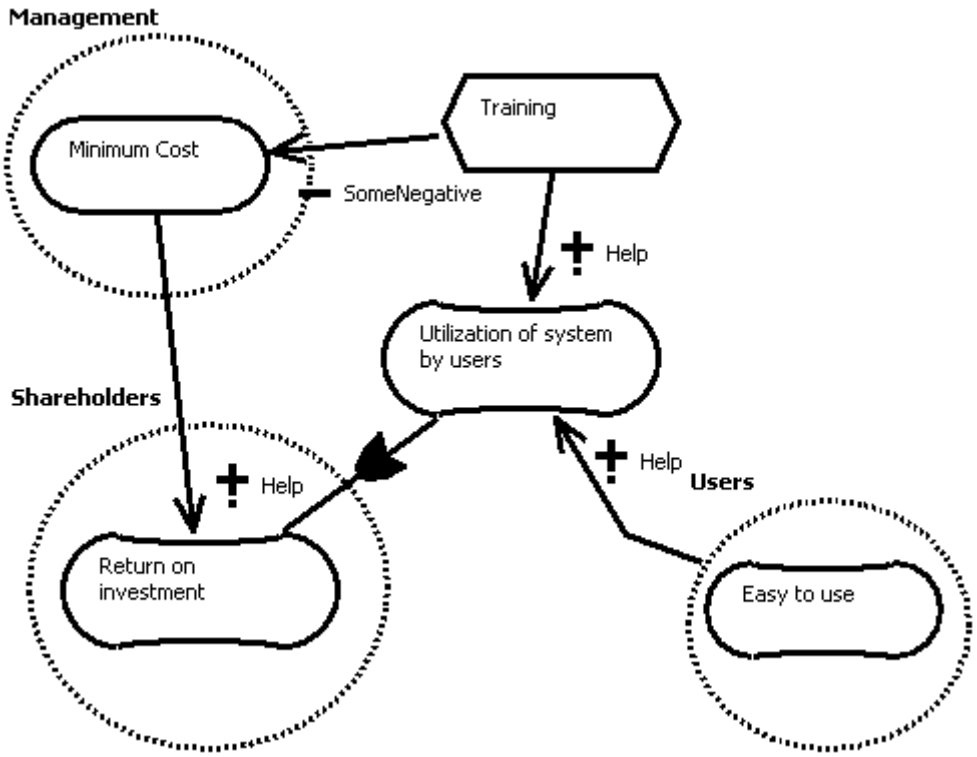


Figure 29. High-level View of Actor Concerns

Once the high-level GRL model is developed, the security catalogue can be imported. This creates a GRL diagram with the definitions found in the catalogue. The catalogue model is integrated by linking authentication tasks to the cost. The card key, biometric and password tasks contribute to the cost (*Some Negative, Hurt* and *Some Positive* respectively). Then, encryption has a side effect on the performance of the system. This side-effect is modelled with a *Some Negative* correlation. Finally, performance has an influence on the usability of the tool, represented with a *Some Positive* contribution. The integrated GRL diagram is presented in Figure 30.

Next, operational and architectural aspects of the system are modeled with a UCM. The model has three main components, corresponding to users, servers and clients (Figure 31). A request to a Web application is represented as a path starting from the users and going to the client, who verified the request. If it is an invalid request (represented with an OR fork), an error message is sent back to users. However, if the request is valid, users provide authentication information, which is sent to the authentication service. A dynamic stub is used to model different implementations of authentication. If an error

occurs during authentication, the client sends back an error message to the users, and if not, the request is sent to the encryption module. Then, the server decrypts the request and processes it. A log is written on the server when, in parallel (modelled with an AND fork), the result is sent to the users.

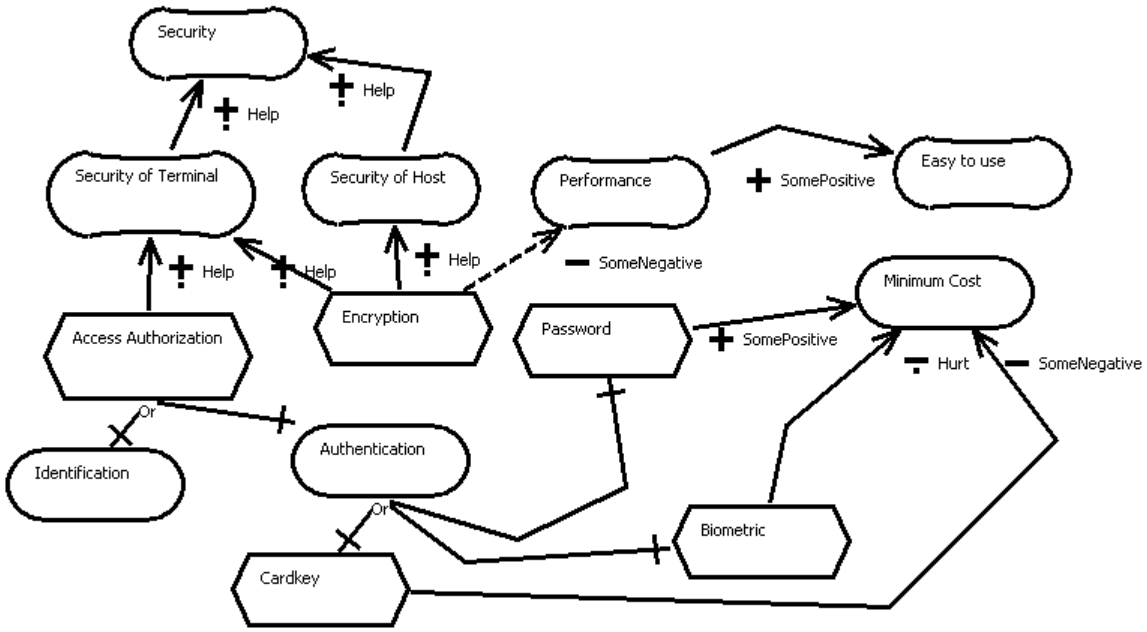


Figure 30. Integration of the Security Catalogue

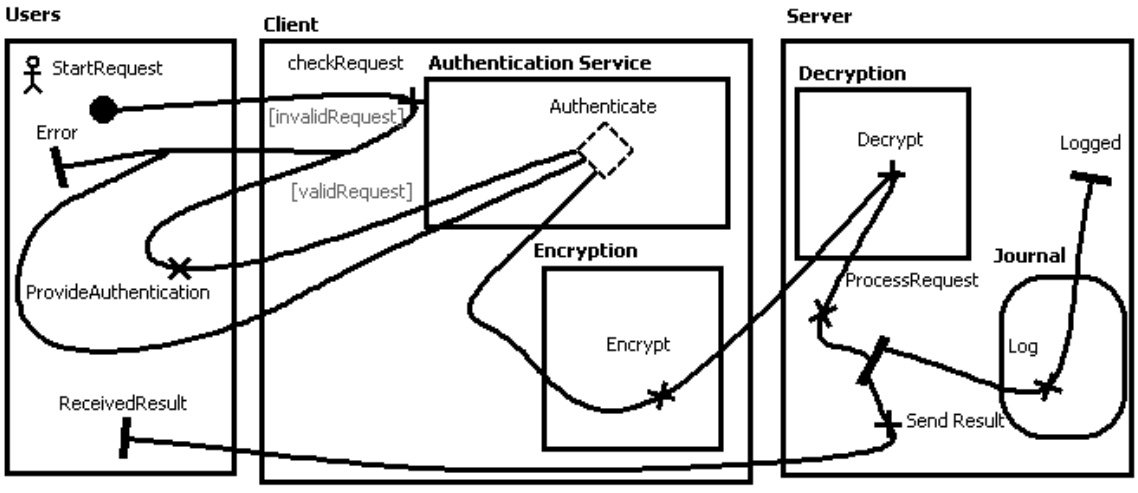


Figure 31. Web Request UCM Model

3.6 Chapter Summary

In this chapter, jUCMNav was enhanced to support GRL. It integrates both sub-notations of URN using a graphical editor and different Eclipse views. In section 3.1, we presented the requirements and rationales that drove the development of the tool. Then, the integrated metamodel for URN was described (section 3.2), which includes a metamodel for the abstract syntax and a metamodel for the tool implementation. Section 3.3 explained in details the architecture and implementation of jUCMNav, as well as how GRL is supported. Then, supporting reusable model, through GRL catalogues, was detailed in section 3.4. This section also includes the description of a security catalogue, which is reused in section 3.5 to develop a simple Web-application case study that uses jUCMNav.

The next chapter will address the new GRL analysis mechanisms developed in jUCMNav. Also, it will explain and show how to link GRL and UCM elements, and will describe how to use these links in model analysis.

Chapter 4 Analysis of URN Models

By providing access to the complete URN model, jUCMNav can offer novel analysis mechanisms. In this chapter, the new concept of GRL strategies is presented. It is based on a new, extensible analysis algorithm that uses numerical evaluations. In addition, a new metric associated with actors is described. To measure the impact of GRL strategies on the architectural aspects, traceability links are developed between the two URN sub-notations.

4.1 A New Evaluation Algorithm

This section presents a new evaluation algorithm used to measure the satisfaction level of GRL intentional elements. Using a numerical evaluation scale, this evaluation mechanism tends to be easier to use than the typical qualitative scale. Also, an adaptable algorithm is used that deals with all intentional links in the model.

4.1.1 From Qualitative to Quantitative Evaluations

In GRL, intentional element satisfaction levels are shown graphically using a qualitative scale – satisfied, weakly satisfied, undecided, conflict, weakly denied and denied (see Figure 4 on page 12). During the project's requirements elicitation phase, we realized that some users are interested in having a quantitative interpretation of satisfaction levels. The advantage of such approach is the larger range (granular representation) of evaluations. It is particularly useful to represent weakly satisfied/denied labels. In addition, numerical evaluations are easier to understand, particularly for new users of the notation.

The chosen numerical representation of the satisfaction level creates values between -100 (denied) and +100 (satisfied), which is a simple and yet intuitive range of values. In the qualitative representation, there are two labels with similar meaning: unknown and conflict. The difference was that in the first case, the user-defined evaluations do not allow calculating an evaluation for a particular element whereas, in the second case, the

link labels generate conflicting evaluations. Because the proposed evaluation algorithm (section 4.2) resolves conflicts automatically, there is no numerical representation of the conflict label used in the quantitative scale.

Name	*Qualitative Representation*	*Quantitative Representation*
Satisfied (Satisficed)		100
Weakly Satisfied (Satisficed)		1 to 99
Unknown		0
Weakly Denied		-1 to -99
Denied		-100

Table 5 Default Correspondence between Qualitative and Quantitative Evaluations

In jUCMNav, both qualitative and quantitative representations are used. In addition, intentional elements are optionally color-coded with shades varying from red (-100) to green (+100). The default value for elements is unknown, or 0 (yellow).

The numerical values represent an approximation of the satisfaction level of intentional elements. Due to the fuzzy nature of non-functional requirements, it is not possible to measure their satisfaction precisely. For example, usability of a system is a requirement that is relative to the user's perception. Some users can consider a system usable when others are unable to use it. Hence, an element that has an evaluation of 100 (or -100) is defined as an element that is sufficiently satisfied (or denied).

4.1.2 Algorithm

Using numerical labels for element satisfaction requires the development of a new GRL analysis algorithm. With the various domains where GRL is used, the evaluation algorithm is required to be flexible and adaptable to different contexts. Furthermore, even if the GRTool algorithm [18] and the NFR framework algorithm [13] inspired some parts of the proposed algorithm, these algorithms are semi-automated and need user inputs to resolve conflicts generated during evaluations. The new GRL algorithm is a fully-automated algorithm with an automatic conflict resolution mechanism. In addition, it uses

all the links in GRL models (including dependencies, which were not considered in previous algorithms).

From an initial set of evaluations assigned to intentional elements (often the leaves of the graph), the evaluations are propagated to the top-level intentional elements via the various links in the model (decompositions, contributions and dependencies). For a particular element, the evaluation is first calculated from its decomposition links, as a standard AND/OR graph [39].

In a AND decomposition, the result corresponds to the minimum evaluation of the sources nodes. As shown in Figure 32, two elements with 75 and -38 labels result in an evaluation of -38. For the OR decomposition, the result corresponds to the maximum evaluation of the source nodes. In this example, it corresponds to an evaluation of 75.

As explained in the preceding chapter, decomposition type is an attribute of the destination element. This is constraining the creation of models with only one type of decomposition per intentional element. However, this design decision greatly simplifies the representation and readability of the diagrams. In spite of this restriction, one is able to model an intentional element that requires two decomposition types by decomposing the initial element into two sub-elements in a sum-of-products form or product-of-sums form (similar to a Boolean expression).

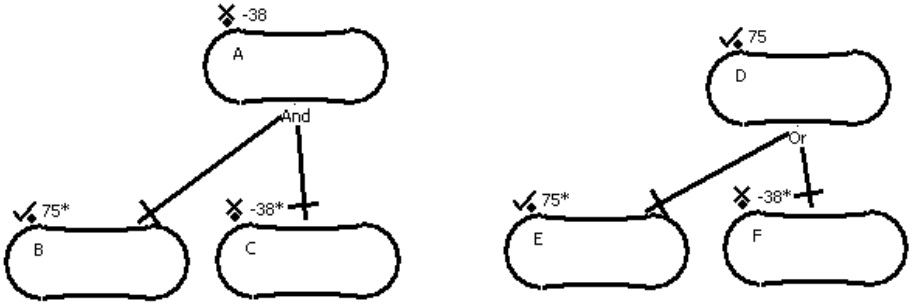


Figure 32. Decomposition Evaluations

Once evaluations for decompositions are calculated, the propagation algorithm evaluates contribution links. The implemented algorithm evaluates the impact of the satisfaction of contributing elements. In addition, this solves the conflict label assigned to most of elements with multiple contributions in the original GRL evaluation algorithm.

For each contribution x of a destination element with N contributions, the satisfaction level of the source element and the contribution level are used (described in Algorithm 1). Note that contributions with unknown evaluation as source elements are not considered in the algorithm. This behaviour allows viewing immediately the impact of contributions on the higher-level intentional elements, even if other contributions are set to unknown.

The contribution level, LEV_x, is given a numerical value between -1 and 1 according to the contribution type on the link (1 for *make*, 0.5 for *help*, 0.25 for *some positive,* 0 for *unknown,* -0.25 for *some negative,* 0.5 for *hurt,* and -1 for *break*). The satisfaction level of the source element, $NEVAL_x$, is normalized to a value between 0 (denied) and 100 (satisfied). The normalized evaluation is multiplied by the contribution level. The results of each of the contributions are added and normalized to provide the total contribution, *TCON*, a value between -100 and 100.

Name: Contribution Evaluation
Inputs:
- NEVAL: int[]
- LEV: int[]
- TOLERANCE: int

Outputs:
- TCON: int

$$TCON = \sum_{x=1}^{N} NEVAL_x \times LEV_x$$

if (*TCON* >= |100|)
then
    TCON = 100 * (TCON/|TCON|)
endif
if ((*TCON* >= (100 – *TOLERANCE*)) **and** ($LEV_{x=1..n} \neq 1$))
then
    TCON = 100 - (1 + *TOLERANCE*)
else
    if ((*TCON* <= (-100 + *TOLERANCE*)) **and** ($LEV_{x=1..n} \neq -1$))
    then
        TCON = -100 + (1 + *TOLERANCE*)
    endif
endif

Algorithm 1 Contribution Evaluation Algorithm

The normalized evaluation is calculated using a tolerance attribute, *TOLERANCE*, which is set to 0 by default. This parameter is configurable, and in jUCMNav, it can be modified by the user through the tool's Preference page. The tolerance defines the range of values that are considered satisfied or denied. For example, with a tolerance of 10, evaluations between 90 and 100 are considered fully satisfied while evaluations between -90 and -100 are considered fully denied. For most cases, the default tolerance is sufficient. However, in some situations, one can modify this value to fit the context of the model.

The second part of Algorithm 1 normalizes the contribution result to a value between -100 + (1 + *TOLERANCE*) and 100 - (1 + *TOLERANCE*) , corresponding to weakly denied/satisfied, if none of the contributions are denied/make contributions. This leads to a behaviour where an infinite number of help contributions (positive but insufficient) still results in a weakly satisfied evaluation.

Once the contributions for an element are evaluated, the result is added to the result from the decompositions (0 if no decompositions). The result is again normalized between -100 and +100 if it is out of bounds. Figure 33 shows typical examples of single contribution evaluations.

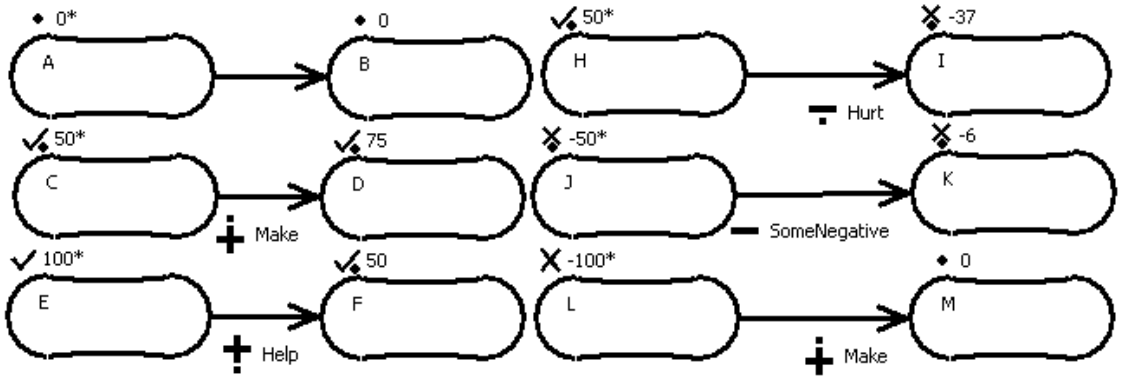


Figure 33. Contribution Evaluations

Finally, the dependencies are evaluated. A dependency is defined as an element that needs another element to be satisfied. It can never have a higher evaluation than the element it depends on. Thus, the algorithm uses the *minimal* value among the dependees. If this value is less than the result from the preceding steps, the final result corresponds to the dependee value.

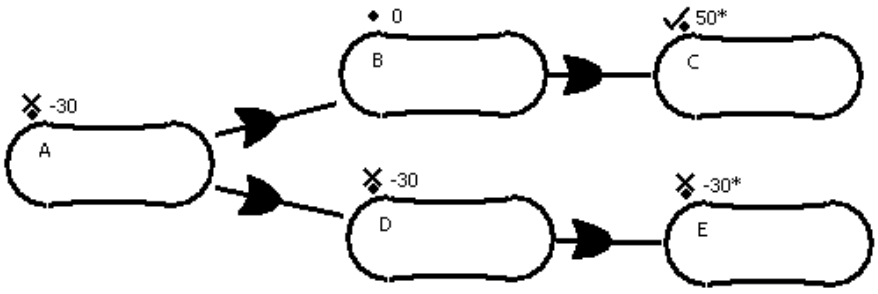


Figure 34. Dependency Evaluations

Figure 34 shows a case where an element A depends on two other elements, B and D. Those two elements also depend on elements C and E respectively. By default, evaluations are set to 0. Element C does not influence the evaluation of B because it is greater than the default evaluation. However, element E is less than the default evaluation of element D, which causes D's evaluation to become -30. This value is in turn propagated to element A.

4.2 GRL Strategies

The evaluations assigned to intentional elements are based on many aspects, such as design decisions, stakeholders, organizational priorities, user beliefs and many other variables. The concept of GRL *strategies* is developed to compare the overall results of those variables on the models. It provides two different analysis labels on the model: one for intentional elements and one for actors.

4.2.1 Intentional Element Labels

GRL strategies are defined as user-defined sets of initial evaluations. This approach is a flexible replacement to belief evaluations, which was hard to use in tools like OME.

As shown in the strategies metamodel (Figure 35), the strategies (*EvaluationStrategy*) can be grouped using *StrategiesGroup*. Groups and strategies are also subclasses of *URNmodelElement*, and inherit its attributes (id, name and description) in the implementation metamodel. Each strategy also has an author attribute, which is used for traceability to the originating stakeholder. Like beliefs, strategies are hypotheses and decisions based on a given context.

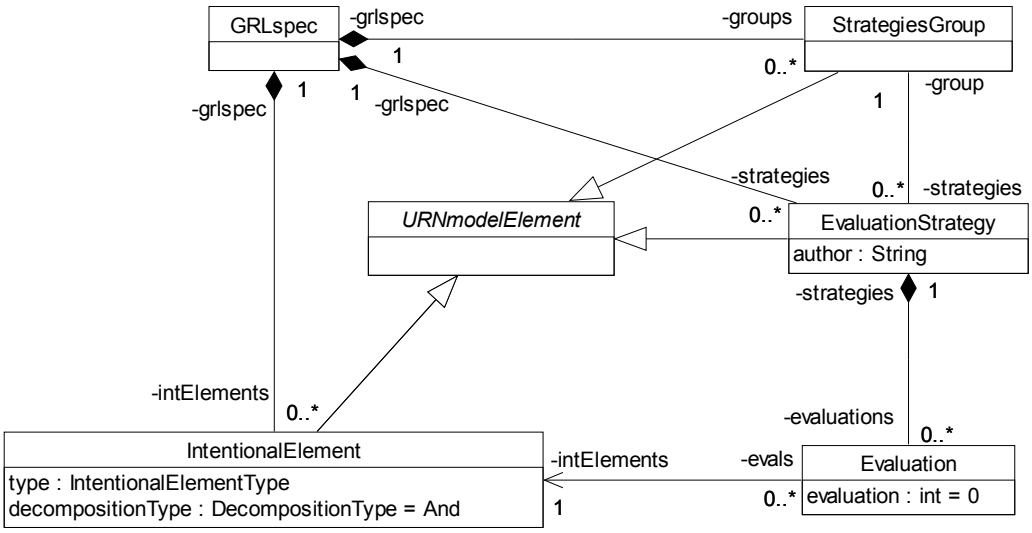


Figure 35. Abstract GRL Strategies Metamodel

Strategies are implemented in jUCMNav using a new Eclipse view, the *Strategies View*, which allows creating, grouping, modifying, evaluating, and deleting strategies. Once a strategy is selected in this view, users can access and modify initial element evaluations using the *Property View*. Figure 36 shows the selection of a strategy through the Strategies View, the result in the editor (colors, and qualitative/quantitative evaluation labels) and the editing of the evaluation level of element identification through the Property View.

By default, all evaluations are set to 0. Then, when users modify an evaluation, the propagation algorithm is applied on the fly and the results are shown immediately. To distinguish user-defined from calculated evaluations, a "*" is added to user-defined evaluation labels. In addition, the implementation allows users to modify evaluations of any elements in the model. When a calculated evaluation is considered invalid, it can be modified directly without affecting evaluations of lower-level elements.

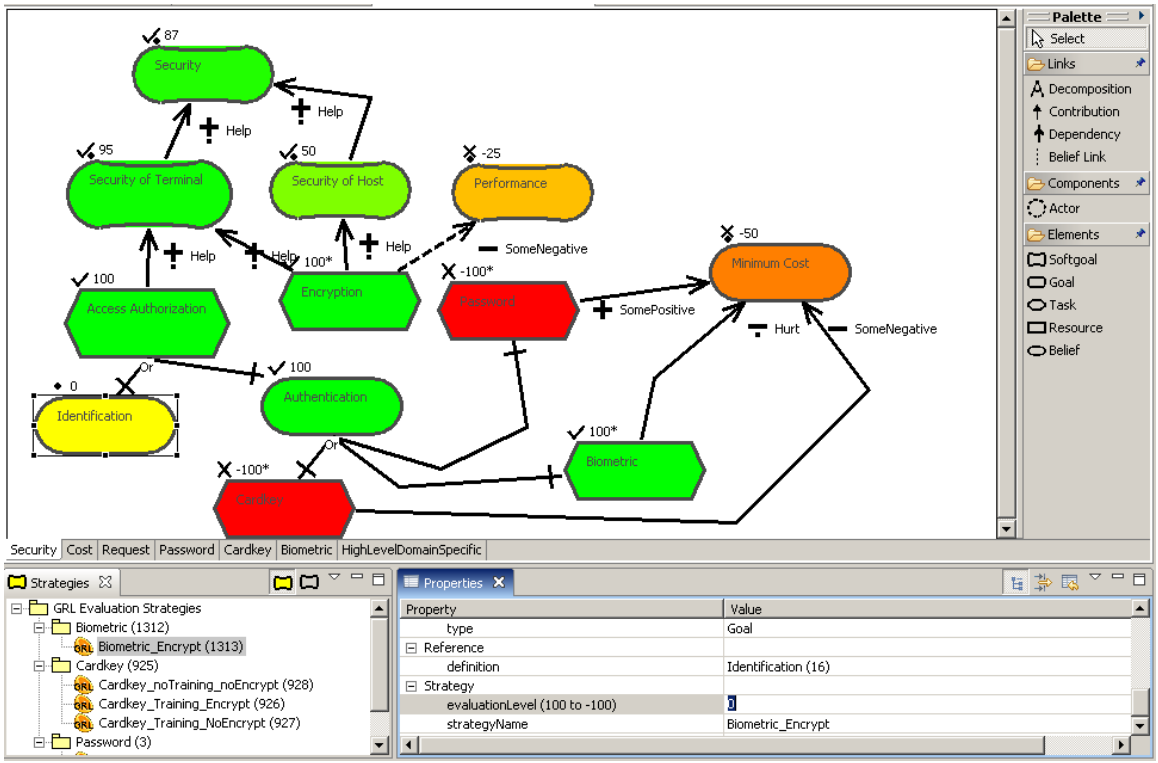


Figure 36. Modification of Evaluation for a GRL Strategy

The evaluations that are persistent (inserted in the model) are the user-defined evaluations. In the current implementation, only one propagation algorithm is available. However, in the future, if new algorithms are implemented, this behaviour will allow users to change the propagation algorithm at run-time.

The implementation of the algorithm is generic and open as it is based on the *strategy design pattern* [16]. This pattern offers the possibility to easily implement other propagation and evaluation algorithms. To implement such extensions, the developer uses Eclipse extension points. Then, in jUCMNav, users will be able to choose which algorithm to apply to their strategies, through the *Preference Page*. In addition, the implementation of GRL strategies will allow one to apply a strategy locally, to fit in its context.

```
Name: Propagation
Inputs:
    - GRLmodel: GRLspec
Outputs:
    - evaluations: HashMap

List elementReady = ∅
List elementWaiting = ∅
HashMap evaluations = ∅

for each element in GRLmodel
{
        element.linkReady = 0
        if (element initialized in currentStrategy)
                elementReady.add(element)
        else
                elementWaiting.add(element)
}

while (elementReady.size() > 0)
{
        element = elementReady.get()
        elementReady.remove(element)
        evaluations.add(element, calculateEvaluation(element))
        for each link l in element
        {
                if (element is source of l)
                {
                        destination = l.destination
                        destination.linkReady++
                        if (destination.linkReady == destination.totalSourceLink)
                        {
                                elementWaiting.remove(destination)
                                elementReady.add(destination)
                        }
                }
        }
}
```

Algorithm 2 Pseudocode for Propagation Algorithm

Extension points are interfaces which must be implemented. The propagation/evaluation extension point has four functions that must be implemented:

- **public** void *init*(EvaluationStrategy strategy, HashMap evaluations);
- **public** boolean *hasNextNode*();
- **public** IntentionalElement *nextNode*();
- **public** int *getEvaluation*(IntentionalElement element);

The classes that implement this interface are called by the *EvaluationStrategy-Manager*, a singleton object responsible of controlling the access to the strategies. It calls *init* with a new strategy to apply. The arguments for this function are the selected strategy and a hash map of the user-defined evaluations. Then, the propagation algorithm is defined through *nextNode* function, responsible to return elements ready for their evaluation (all their lower-level elements were evaluated). Finally, *getEvaluation* is the function which implements the evaluation algorithm.

The default propagation algorithm is shown in Algorithm 2. It is implemented in jUCMNav using the four functions from the extension point interface. It is using two lists, one for elements that are ready to be evaluated (*elementReady)*, which correspond to elements with user-defined evaluations for the strategy, and the second list for the other elements (*elementWaiting)*. First, elements in the ready list are processed. Once the calculated evaluations are available, it increments a counter for each outgoing links (associate to the destination elements). Once this counter is equal to the total number of incoming links on an element, it is switch from *elementWaiting* to *elementReady* list. This is executed until the *elementReady* list is empty. If not all the elements are processed, the default evaluation is used for them (0).

4.2.2 Actor Labels

Combining agent and goal modelling offers the possibility to use both constructs in the analysis. However, the actors in GRL were not used in previous analysis mechanisms. In our tool, for a given strategy, a global satisfaction label is associated to actors, which helps visualize negotiations between stakeholders.

This proposed label is calculated based on the intentional element references bound to actor references. The label corresponds to a value between -100 and 100, com-

puted from the *priority* and the *criticality* of contained intentional element references. These two attributes can take the values high, medium, low, or none.

In order to model actor concerns on particular goals/requirements, priority and criticality are associated to references. Different actors can consider concerns differently. Priority and criticality give the flexibility to deal with this situation. In addition, intentional element references can be used for actor's requirements negotiation. For example, in a situation where two actors have conflicting goals, with different visions of the goals, the labels allow modellers to evaluate the impact of strategies on the actor's satisfaction. Through the comparison of strategies, one will be able to choose the strategy that maximizes the satisfaction of the actors, or that satisfies a particular actor for a particular context.

First, for a specific actor, the algorithm iterates through the actor list of bound intentional element references. Note that multiple element references associated with the same definition can be bound to the same actor. They are considered as different intentional elements (to allow usage of intentional element in different contexts). Using both priority and criticality, the evaluation of each element is multiplied by the corresponding factor (1.5 for high, 1.0 for medium, 0.5 for low and 0 for none), and computes the average per bound intentional element. Then, it sums both evaluations and normalizes the result between -100 and 100.

An example of actor evaluation with multiple intentional elements is shown in Figure 37. In this example, Actor1 and Actor2 have both the same intentional element. Element A has a low priority and no criticality for Actor1 and it has no priority and a high criticality for Actor2. In this case, the satisfaction of Actor2 is higher than Actor1.

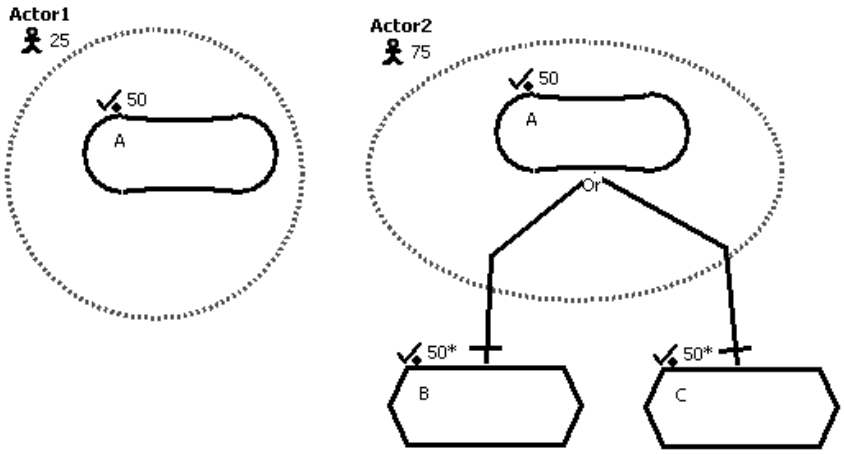


Figure 37. Actor Evaluation Labels

4.3 Using GRL Analysis

To demonstrate how to use the analysis mechanism presents in the preceding section, the Web application case study presented in 3.5 is revisited. GRL analysis is used to determine how well security is satisfied based on various options, as well as to what extent the stakeholders are satisfied.

Usually, user-defined evaluations are set to lower-level elements. In the Web-application GRL model, those elements correspond to operational tasks. Because of the operational, concrete properties of tasks, their satisfaction values are Boolean (-100 or 100).

The first step in the analysis consists of creating the strategy groups. In this example, groups are created based on the authentication methods evaluated (cardkey, biometric or password). Those authentication methods are never combined in the model because only one of those is necessary (OR decomposition). For each of the authentication methods, there are strategies that evaluate the impact of enabling/disabling encryption and offering, or not, training to users. There are four strategies for each of the three authentication methods: encryption with training, encryption without training, no encryption with training and no encryption without training.

The next step consists of assigning *criticality* and *priority* to intentional element references. In the Web application model, users are concerned by the usability of the tool. However, it is not a priority, which is captured by no priority and a low criticality for this

element. In addition, shareholders are highly concerned with the return on their investment, resulting in a high priority and high criticality. Finally, management is concerned in reducing the cost. High priority and medium criticality are assigned to the cost softgoal.

Figure 38 shows a GRL graph in jUCMNav with the most interesting elements in the model for the strategy with password, encryption and training. Note that the actor evaluation labels are located at the top left corner of the actor boundaries, next to the stickman icon.

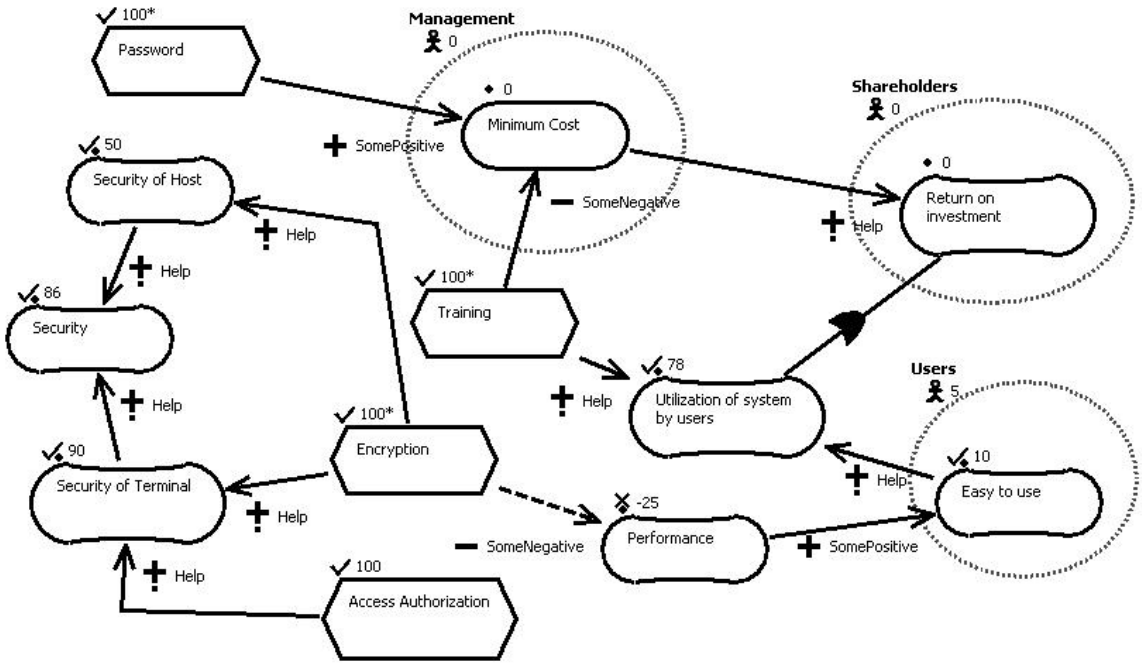


Figure 38. Password – Encryption – Training Strategy in jUCMNav

Using the strategies, it is possible to compare the satisfaction of actors and intentional elements, based on various functional decisions. Table 6 shows the user-defined evaluations for the password strategies, as well as the resulting labels for intentional elements and actors.

For the password strategies, encryption must be enabled to maximize security. However, enabling encryption reduces performance. Also, the operational choices do not influence the identification goal, which is unknown (0) for all strategies. Enabling encryption and offering training to users greatly increase the satisfaction of utilization of the

system softgoal. Finally, to maximize the actor satisfaction, the strategy with encryption and without training should be used.

Using the export extension points, jUCMNav supports exporting GRL strategies with results to comma-separated value files (CSV). These files can be imported by spreadsheet applications to generate tabular representations of the strategies. The files are created with the scenario names as row headers, and the actors/intentional elements as column headers. Then, each cell corresponds to an element evaluation for the corresponding strategy. In addition, user-defined evaluations are distinguished from calculated evaluation by adding an "*" at the end of the value. The table generated from the CSV file that contains the 12 strategies of our example is available in Appendix B.

Password Strategies					
		Encryption – Training	Encryption - No Training	No Encryption – Training	No Encryption - No Training
User-Defined Evaluations	Encryption	100	100	-100	-100
	Training	100	-100	100	-100
	Cardkey	-100	-100	-100	-100
	Password	100	100	100	100
	Biometric	-100	-100	-100	-100
Calculated Evaluations	Security	86	86	38	38
	Security of Terminal	90	90	50	50
	Security of Host	50	50	0	0
	Access Authorization	100	100	100	100
	Identification	0	0	0	0
	Authentication	100	100	100	100
	Minimum Cost	0	25	0	25
	Performance	-25	-25	0	0
	Return on Investment	0	28	0	31
	Easy to use	10	10	0	0
	Utilization of the system by the users	78	28	50	0
Actors	Shareholders	0	42	0	46
	Users	5	5	0	0
	Management	0	31	0	31

Table 6 Password Strategies for Web Application Case Study

4.4 Linking Goals and Scenarios: URN Internal Links

The GRL strategies we introduced allow studying the impact of intentional elements on goal and agent models. However, these intentional elements may also have an influence on the architectural and scenario models. To deal with such analysis, this section presents a new construct in URN to support internal links between UCM and GRL elements.

4.4.1 Link Definition and Implementation

Integrating UCM and GRL views in the same tool allows for the creation of various traceability links between elements from both notations. Those links can help improving the consistency between the URN views during model evolution.

The GRL syntax [25] has a simple construct, *non-intentional element*, which defines references to external models. However, it does not have any impact on the GRL model analysis or on the external model. The concept of *URNlinks* is introduced to measure the impact of a modification to any evolving GRL/UCM diagram on the other aspects of the model. As shown in Figure 25 on page 44, *URNlink*s have *from* and *to* elements, which are of type *URNmodelElement.* In the metamodel, most of the URN constructs inherit from this superclass.

Even if the metamodel defines links between any element types, the current implementation supports only links from GRL to UCM elements. In addition, we currently limit the number of links to one for UCM elements. This limitation is to simplify the UCM analysis based on the strategies. The current constructs supporting links in jUCM-Nav are intentional elements and actors for GRL and responsibilities, components, and maps for UCM.

Typically in URN, tasks and resources are the intentional elements that have the most chances of being used in links. They represent concrete aspects of the solution. However, in early requirements stage, one can use links at a higher level, with abstract goals. In addition, links are habitually created between actors and components.

Links are created through a new dialog (see Figure 39), which also allows viewing and deleting links in the model. This dialog includes attributes such as the selected GRL element name, type and description at the top of the dialog. Then, on the left, the list of current links for an element is available. Finally, new links can be created using the

two drop-downs. Once the links are created, a symbol (yellow triangle) is displayed at the top-left corner of the element label (see Figure 41).

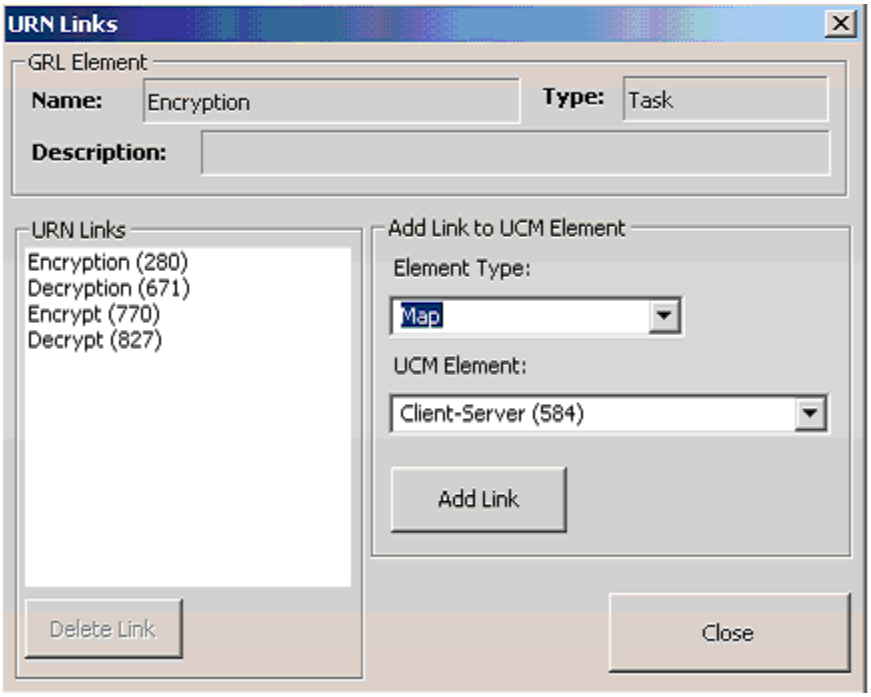


Figure 39. URN Links Definition in jUCMNav

Using the links and GRL strategies, it is now possible to evaluate the impact of a strategy on the UCM model. This is achieved by associating evaluations from GRL elements to the link destination elements (UCM components, responsibilities or maps). Even if actors have evaluation labels, their evaluations are not associated with UCM models. Those labels are global satisfaction levels, and they do not have any impact on the operational aspects.

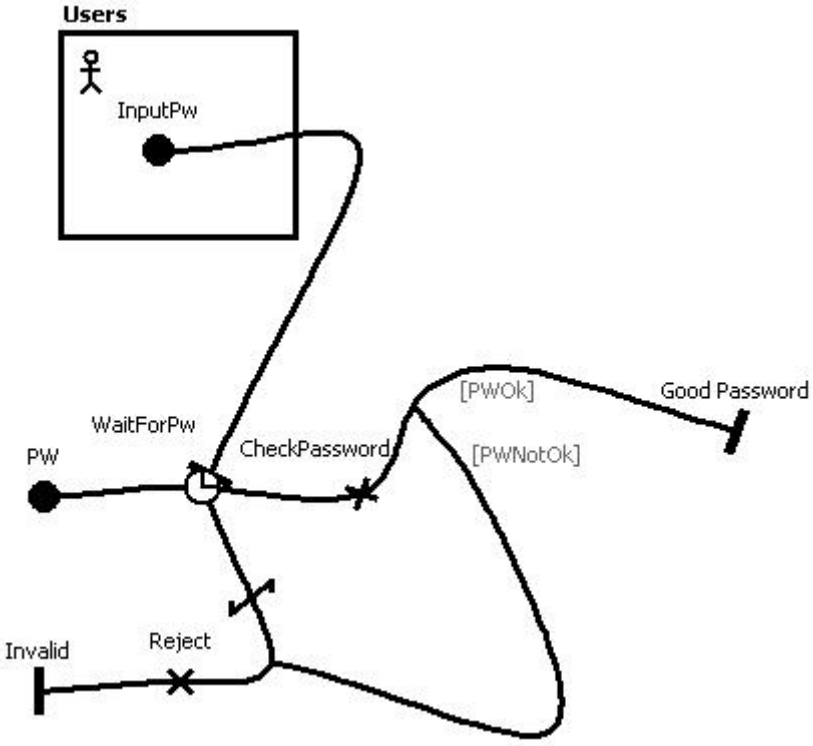
Based on the element type, the evaluation in UCM can be interpreted differently. In the typical situation, UCM elements have associated evaluations of 100, 0, or -100 (satisfied, unknown or denied). These values mean that an element is available or not in the current architecture. However, in some cases, weakly satisfied (or denied) evaluations can be displayed in the UCM model. This usually indicates that the GRL model needs further refinement.

Even if the current *URNlink*s already have an impact on UCMs, the upcoming support for UCM scenario in jUCMNav will improve greatly the analysis possibilities based on the links. This will allow one to evaluate the impact of a strategy on a scenario.

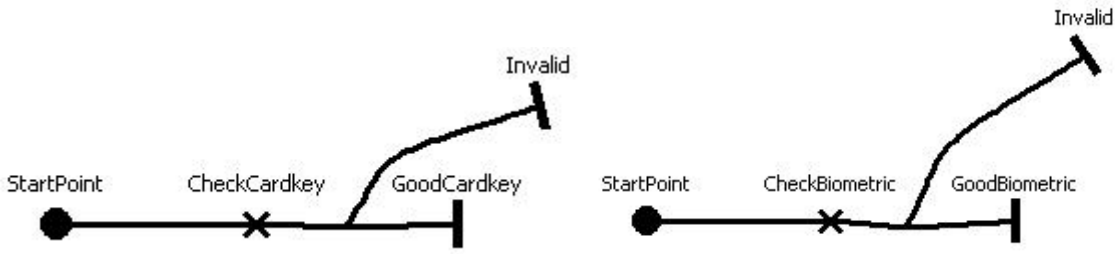
For example, for links between maps in a dynamic stub and GRL, it would be possible to use the evaluations from the strategies in the selection conditions for the stub.

4.4.2 Using URN Links

In this section, URN links are added to the Web application case study. Then, the analysis of the UCM through those links is presented.



a) Password Map



b) Cardkey Map

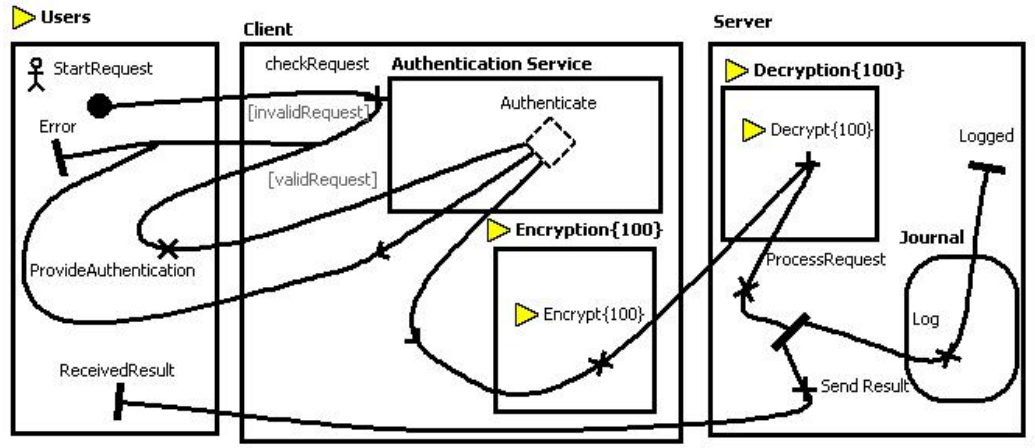
c) Biometric Map

Figure 40. UCM for Authentication Mechanisms

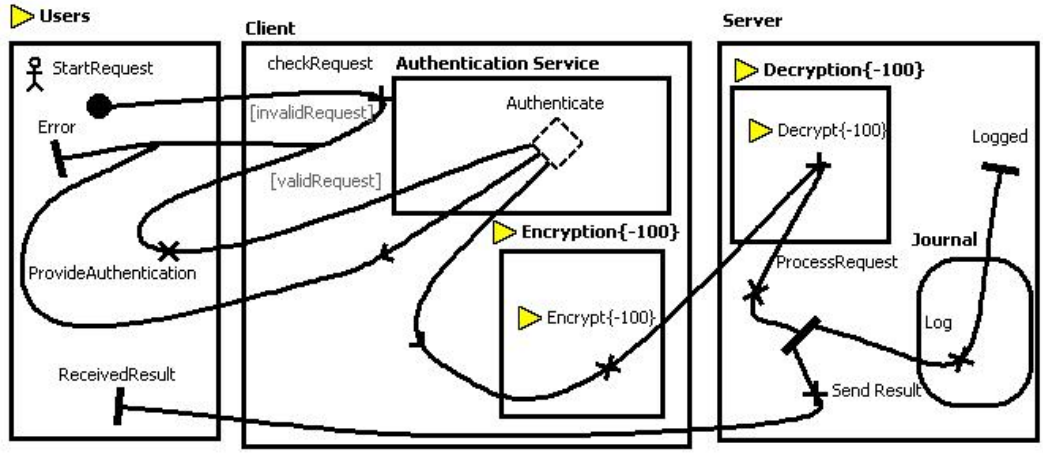
Maps for the Authenticate dynamic stub in Figure 31 on page 54 are first created. These plug-in maps are shown in Figure 40. For Cardkey and Biometric, there is a branch that

depends on the authentication information. For Password, the system waits for the user to enter his password (Pw). If a timeout occurs, it rejects the password. If the password is entered in a timely fashion, the system verifies its validity.

In this model, URN links are created from each of the authentication tasks of the GRL model (Password, Biometric, and Cardkey) to each of their corresponding plug-in maps (bound to the Authenticate stub). Other URN links are set between the User actor and the User component, which correspond to the same entity, as well as from the Encryption task to the UCM Encrypt and Decrypt components and to the UCM Encrypt and Decrypt responsibilities.



a) Cardkey strategy with encryption



b) Cardkey Strategy with no Encryption

Figure 41. UCM Views Based on the Selected GRL Strategy

Figure 41 shows the result of two GRL strategies on the UCM view. UCM constructs that have a defined URN link are identified with a yellow triangle at the left of their label. In this model, if the Encryption task is satisfied (100), then, corresponding components and responsibilities are available. However, if the task is denied (-100), the corresponding components and responsibilities are no longer part of the scenario model.

4.5 Chapter Summary

In this chapter, we presented novel analysis mechanisms for URN models. These mechanisms are focused on GRL models. First, we have described a new evaluation algorithm that uses numerical evaluations. This feature is easier to use and gives more flexibility to the user than preceding qualitative evaluations. However, the qualitative labels are kept in the implementation as graphical indicators. Then, the GRL strategies presented in section 3.2 enables the definition and comparison of different sets of initial evaluations. This new concept will be proposed for standardization in GRL [25] [47]. Strategies have attributes for traceability, which allow multiple users to define their own sets. In addition, a new metric for actor evaluation improves coarse-grained model analysis.

Section 4.3 presented an example of the analysis mechanism in GRL using the Web application case study. Then, in section 4.4, we presented the concept of URN links, which enables a tighter integration of UCM and GRL. Traceability links are used to provide feedback on the UCM view based on selected GRL strategies.

In the next chapter, we present how to link GRL elements from/to external requirements. The analysis concepts to be presented in this chapter are used to provide further traceability capabilities between general requirements and URN models.

Chapter 5 Linking and Evolving Requirements

Using URN models developed with jUCMNav, it is possible to create links with external requirements. This chapter describes this approach based on a Requirements Management System (RMS), namely Telelogic DOORS, to manage external requirements.

Section 5.1 explains how URN models are exported in a DOORS-compatible format by jUCMNav. Then, section 5.2 describes the DXL library that supports importing URN and how the internal traceability is managed. Finally, the mechanisms for requirements and model synchronizations are illustrated in section 5.3.

5.1 Exporting URN Models to DOORS

Using URN models in DOORS can be done by developing extensions using *DOORS eXtension Language* (DXL) scripts [27]. The decisions about which elements to export in the scripts are driven by a few principles and requirements described in the first subsection. The support for exporting URN models is implemented directly in jUCMNav, as an extension point. The implementation is discussed in the second sub-section.

5.1.1 Principles and Requirements for Exporting URN

Requirements Management Systems were developed to manage structured elements, mainly textual requirements. However, using these systems to manage graphical models such as URN required adapting the metamodel to the tools structure. As discussed previously, elements in DOORS are stored in *formal modules* and are associated together with links stored in *link modules.* Using this structure, exported URN models require keeping a global view of the main elements in the models and linking the main elements to external requirements. The export mechanism developed is based on previous works by Jiang *et al*. where they exported UCM models to DOORS [27] (presented in Chapter 2).

Having URN models in DOORS ideally requires supporting all the basic constructs of the notation. These constructs are definitions, references, containers, contain-

ment relationships, and associations. On the other hand, a minimal number of URN elements should be exported, to prevent database and export performance degradation. Thus, the export mechanism should focus on the main semantic elements of the notation that can conceptually be linked from/to external requirements.

Even if DOORS requires dividing URN constructs into modules, the URN diagrams' integrity should be keep. Traceability between diagrams and their elements should be preserved, as well as traceability between references and definitions. URN links, which are useful for traceability analysis, should also be exported. Finally, the dynamic behaviour of GRL, i.e. strategies and their results, should also be available in DOORS.

The export process consists of importing a DXL file, representing the URN model, in DOORS. If the model is imported for the first time, the corresponding URN modules should be created. Those modules correspond to formal modules to store URN elements, and link modules to capture relations between elements. Once the model is created, updating the model should be a matter of reimporting a new DXL file.

To support the URN model in DOORS, a DXL library is installed to provide an application programming interface (API) for URN elements in the export scripts. This API creates and updates the elements in DOORS, and manages the internal links between the elements. It is based on the previously developed library for UCM.

5.1.2 Implementation in jUCMNav

The DXL scripts creation in jUCMNav is implemented as an extension point. As discussed in chapter 3, extension points were developed to export URN models in various formats. Developing a new extension point requires one to develop a new class which implements an export interface. It is hooked to the plug-in in Eclipse using an XML file that defines the configuration of the extension points.

The DXL export mechanism requires two types of files: a DXL script generated by traversing the model instances, and images of the URN diagrams. Diagram images are exported using the image exporter previously developed. DXL scripts and images are saved in the same location, specified by the user.

The jUCMNav algorithm that creates the DXL scripts starts by writing the header of the script which is an include statement of the main DXL script file. Then, an initiali-

zation function is called with the name of the URN model. Next, all element definitions are exported (GRL actors, UCM components, UCM responsibilities and GRL intentional elements). In addition, GRL link definitions, between intentional elements, are exported.

The attributes that are exported are id, name, and description for objects that extend *URNmodelElement*. Other exported attributes are element type (softgoal, goal, task, or resource), decomposition type for intentional elements, and link type, contribution type, source and destination elements for links.

The next step of the algorithm consists of exporting URN diagrams. Each element of the diagrams is exported, excluding link references in GRL and paths in UCM. When elements are bound to containers (GRL actors or UCM components), container ids are also exported. In addition, visual attributes for the diagram elements are exported, such as positions in the diagram (x, y) and width/height of actor references. Finally, the algorithm exports specific attributes such as priority and criticality for intentional element references, and author for beliefs.

To export GRL strategies, the algorithm should access the user-defined and calculated intentional element evaluations. However, intentional element evaluations are not persistent. The strategy manager, which is implemented as a singleton, allows the exporter to provide a strategy and return the evaluation of each intentional element and actor. In the exporter implementation, two different DXL functions are used to distinguish user-defined from calculated evaluations.

Finally, URN links are exported using source and destination element identifiers as attributes. The current implementation of jUCMNav does not support the UCM scenario and device construct, which were supported in the UCMNav tool. Once these constructs become available in the tool, adding them in the DOORS export will be trivial.

Figure 42 shows a DXL script corresponding to the security catalogue from chapter 3. A strategy has been added to the catalogue. The strategy includes satisfied evaluations (100) for Encryption and Password, and denied evaluations (-100) for Cardkey and Biometric.

```
#include "addins/URN/lib/URNUtilities.dxl"
pragma runLim, 0

beginImport( "security" )

intentionalelement( "6", "Security", "Softgoal", "high-level non-functional requirement", "And" )
intentionalelement( "8", "Security of Terminal", "Softgoal", "To achieve security, ", "And" )
intentionalelement( "10", "Security of Host", "Softgoal", "", "And" )
intentionalelement( "12", "Encryption", "Task", "Encryption improved security", "And" )
intentionalelement( "14", "Access Authorization", "Task", "Authorization helps security ", "Or" )
intentionalelement( "16", "Identification", "Goal", "Identified the users", "And" )
intentionalelement( "18", "Authentication", "Goal", "Authenticated the user", "Or" )
intentionalelement( "20", "Cardkey", "Task", "", "And" )
intentionalelement( "22", "Password", "Task", "", "And" )
intentionalelement( "24", "Biometric", "Task", "", "And" )

contribution("106", "Contribution", "contribution", "Help", "0", "", "8", "6" )
contribution("107", "Contribution", "contribution", "Help", "0", "", "10", "6" )
contribution("108", "Contribution", "contribution", "Help", "0", "", "14", "8" )
elementlink( "109", "Decomposition", "decomposition", "", "18", "14" )
elementlink( "110", "Decomposition", "decomposition", "", "16", "14" )
elementlink( "111", "Decomposition", "decomposition", "", "20", "18" )
elementlink( "112", "Decomposition", "decomposition", "", "22", "18" )
elementlink( "113", "Decomposition", "decomposition", "", "24", "18" )
contribution("114", "Contribution", "contribution", "Help", "0", "", "12", "8" )
contribution("115", "Contribution", "contribution", "Help", "0", "", "12", "10" )

grldiagram( "5", "Security", "security-GRLGraph5-Security.bmp", "Security", "" )
  intentionalElementRef( "7", 219,29,"", "6", "Security", "high-level non-functional requirement", "None", "None" )
  intentionalElementRef( "9", 12,80,"", "8", "Security of Terminal", "To achieve security, ", "None", "None" )
  intentionalElementRef( "11", 398,114,"", "10", "Security of Host", "", "None", "None" )
  intentionalElementRef( "13", 363,213,"", "12", "Encryption", " Encryption improved security", "None", "None" )
  intentionalElementRef( "15", 22,189,"", "14", "Access Authorization", "Authorization helps security", "None", "None" )
  intentionalElementRef( "17", 12,310,"", "16", "Identification", "Identified the users", "None", "None" )
  intentionalElementRef( "19", 238,260,"", "18", "Authentication", "Authenticated the user", "None", "None" )
  intentionalElementRef( "21", 134,350,"", "20", "Cardkey", "", "None", "None" )
  intentionalElementRef( "23", 302,352,"", "22", "Password", "", "None", "None" )
  intentionalElementRef( "25", 472,348,"", "24", "Biometric", "", "None", "None" )

strategy( "4", "PasswordEncryption", "", "Jean-François Roy" )
  evaluation( "6", "86" )
  evaluation( "8", "90" )
  evaluation( "10", "50" )
  defined( "12", "100" )
  evaluation( "14", "100" )
  evaluation( "16", "0" )
  evaluation( "18", "100" )
  defined( "20", "-100" )
  defined( "22", "100" )
  defined( "24", "-100" )

endImport
```

Figure 42. DXL Script for a GRL Diagram with a Strategy

5.2 Importing URN Model in DOORS

The DXL scripts generated by jUCMNav can simply be run by DOORS to import the corresponding URN model. This creates the required formal and link modules for the imported model. In addition, based on the function calls in the scripts, the DOORS objects and links representing the URN model elements and relationships are created.

5.2.1 DOORS Structure

DOORS is structured using a hierarchy of projects, folders, and modules. URN models are typically imported into projects that have modules and folders. When a URN model is imported into a project for the first time, a new folder with the URN model name is created, which contains the required formal and link modules. If a folder with the model name is in the project, the library associates the folder with the URN model.

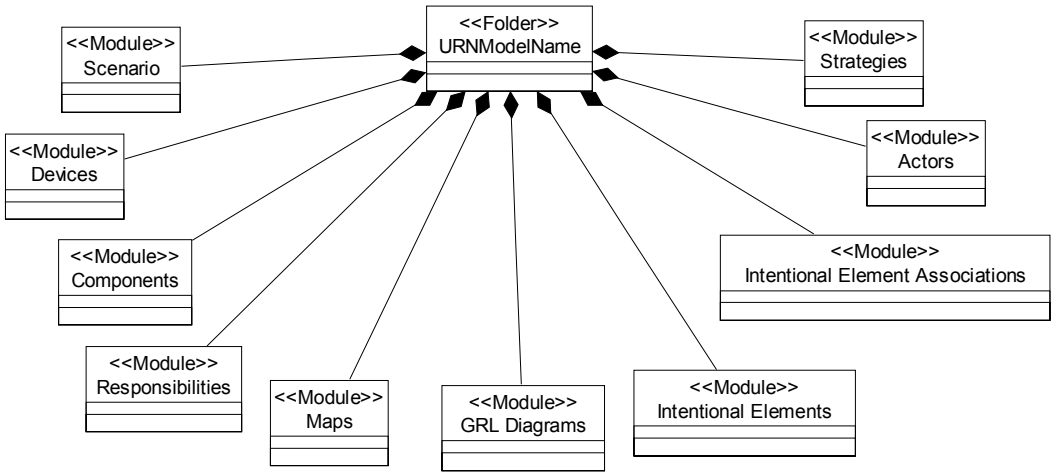


Figure 43. High-Level View of URN Structure in DOORS

Figure 43 shows the structure of the imported model. Various formal modules are created in the root folder. UCM is supported through the Maps, Responsibilities, Components, Devices, and Scenario modules. GRL is supported using five modules: GRL Diagrams, Intentional Elements, Intentional Element Associations, Actors and Strategies.

Definitions are stored in their own modules. Thus, intentional element and actor objects are stored respectively in the Intentional Elements and Actors modules. As shown

in Figure 44, links between intentional elements are represented using three object types, corresponding to the association types. These objects have incoming and outgoing links to their source and destination intentional elements.

The GRL Diagrams module contains all the diagrams and their associate sub-objects (i.e. intentional element/actor references and beliefs). Reference objects in this module are created with links to their definition objects. In addition, beliefs can be associated to intentional element references. This association is represented using a link from belief objects to intentional element reference objects. To manage actor bindings, links are created from bound elements to their actor references. Finally, the Strategies module contains a list of the GRL strategies and their evaluations for each intentional element/actor definition.

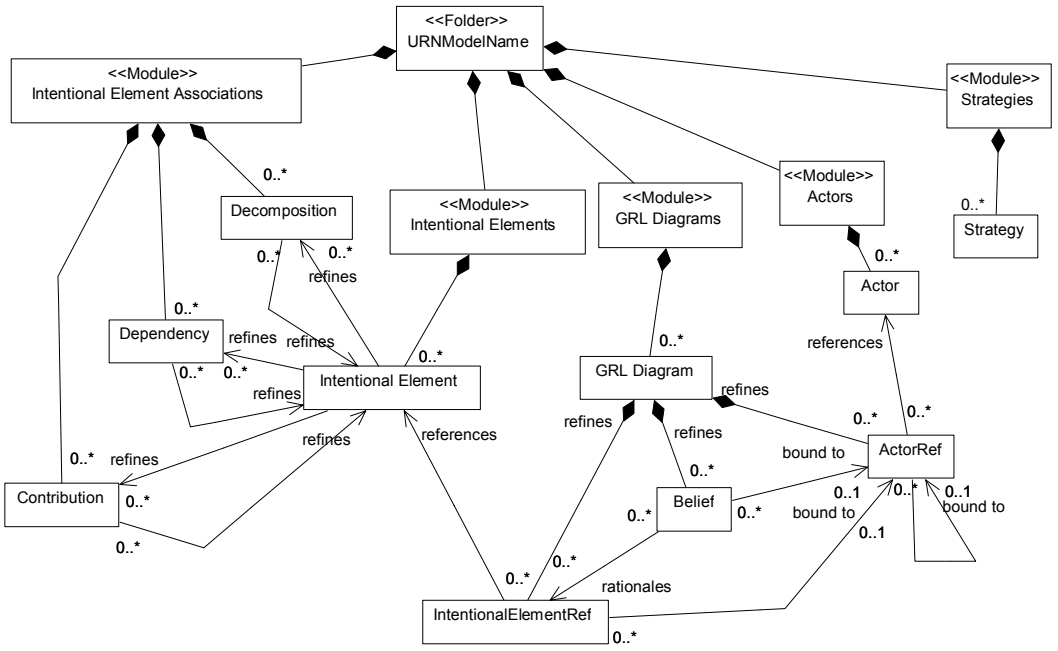


Figure 44. Metamodel of GRL in DOORS

For each module, DOORS views are created. These views define visual attributes of the module, such as the position on the screen and the size of the window, but they also contain the list of attributes to show for the objects. The modules have common views such as full view and standard view, which show all the imported attributes in a module. In addition, there are model management views, such as “Deleted View” and “Suspect

View" (discussed in detail in section 5.3). Finally, each object type imported in modules has its own view, which shows attributes used by this object type. These views are useful when multiple object types are stored in the same modules, such as the GRL Diagrams module (contains GRL Diagram, Belief, ActorRef, and IntentionalElementRef objects).

5.2.2 Internal Links

DOORS links allow creating and navigating traceability associations between objects in formal modules. Links are defined in *link modules*, and have a source object and a target object. When an object is the source of a link, this link is called *outgoing link* for this object, whereas an *incoming link* is a destination link. Even if links have directions, users can navigate through them in either direction. Navigation has been implemented in DOORS using triangle icons (◄ and ►) added to the objects visible in the formal module. Incoming and outgoing links for objects are accessed using these icons.

When dividing the URN model into modules, it becomes necessary to define traceability links to capture internal associations in the model, which we call *internal links.* They are created and updated automatically by the DXL library when a URN model is imported. In the library, once all formal module elements are created or updated, link instances are created. The link modules that are created include the link definitions, consisting of a list of all the object types that can be linked together as well as the direction of these links. In addition, the link modules are used to store the instances of the links.

For URN, there are eight link modules: Bound To, Hosts, Rationales, References, Refines, Requests, Traced By and URN links. Except for URN links, all the other link instances are created automatically at the end of the importing process. For URN links, they are created by DXL scripts generated in jUCMNav.

The internal links are created bottom-up, starting for a lower-level elements to a higher-level one. For example, an intentional element reference has two outgoing links: one to the diagram and another to the intentional element definition.

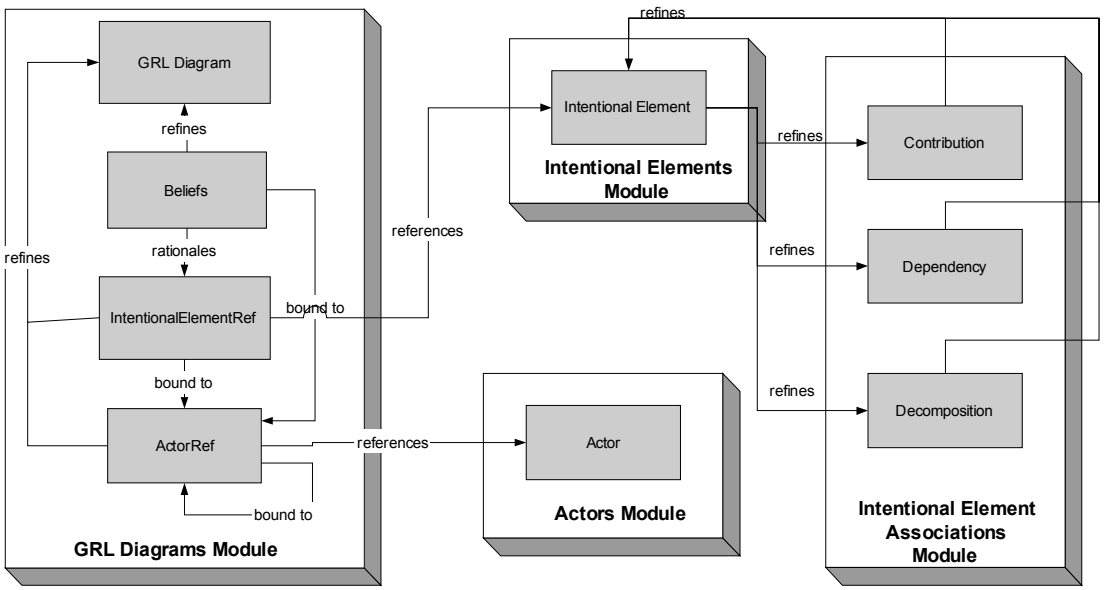


Figure 45. Internal Links in the DOORS URN Folder

5.2.3 DXL Library API

This section is a description of the main functions available in the DXL library used to create and update URN models in DOORS. We focus here on new functions added to support GRL. For further information on UCM functions, please refer to [27].

The API description is divided into four sections, corresponding to the types of elements that are created. Each of the functions presented returns *TRUE* if no exception is generated during the execution.

Definition Objects:

```
bool actor ( string actorID,
             string actorName,
             string theDescription )
```

Parameters:

- *actorID (String):* The identifier of the actor.
- *actorName (String):* The name of the actor.
- *theDescription (String):* The description of the actor.

Description:

This function creates and updates an actor object in the actors module. The key attribute for the module is actorID, which uniquely identifies the object. Other parameters correspond to attributes of the actor object.

```
bool intentionalelement ( string elementID,
                          string elementName,
                          string elementType,
                          string theDescription,
                          string decompositionType )
```

Parameters:

- *elementID (String):* The identifier of the intentional element.
- *elementName (String):* The name of the intentional element.
- *elementType (String):* The type of the element (softgoal, goal, task or resource).
- *theDescription (String):* The description of the element.
- *decompositionType (String):* The type of decomposition of the element (or, and).

Description:

This function creates and updates an intentional element object in the intentional elements module. The key attribute for the module is elementID, which uniquely identifies the object. Other parameters correspond to attributes of the intentional element object. The decompositionType parameter is used to describe the decomposition links associated to the object.

```
bool elementlink ( string linkID,
                   string linkName,
                   string linkType,
                   string theDescription,
                   string sourceID,
                   string destinationID )
```

Parameters:

- *linkID (String):* The identifier of the element link.
- *linkName (String):* The name of the element link.
- *linkType (String):* The type of the link (dependency or decomposition).
- *theDescription (String):* The description of the element link.
- *sourceID (String):* Reference to identifier of the source intentional element.

- *destinationID (String):* Reference to identifier of the destination intentional element.

Description:

This function creates and updates link objects (dependency or decomposition) in the intentional element associations module. The key attribute for the module is linkID, which uniquely identifies the object. This function is used for dependencies and decompositions, which have the same attributes. Other parameters correspond to attributes of the object. SourceID and destinationID are references to the intentional elements module.

```
bool contribution ( string elementID,
                    string elementName,
                    string elementType,
                    string contributionType,
                    string correlation,
                    string theDescription,
                    string sourceID,
                    string destinationID )
```

Parameters:

- *elementID (String):* The identifier of the contribution.
- *elementName (String):* The name of the contribution.
- *elementType (String):* The type of the contribution.
- *contributionType (String):* The label associated with the contribution.
- *correlation (String):* 0 if contribution, 1 if correlation.
- *theDescription (String):* The description of the contribution.
- *sourceID (String):* Reference to identifier of the source intentional element.
- *destinationID (String):* Reference to identifier of the destination intentional element.

Description:

This function creates and updates a contribution object in the intentional element associations module. The key attribute for the module is linkID, which uniquely identifies the object. Correlation parameter is a string that has 0 or 1 as value. It is defined as a string attribute instead of as a Boolean in order to support empty values. Other parameters cor-

respond to attributes of the object. SourceID and destinationID are references to the intentional elements module.

Example:

The following example uses the Web application model developed in preceding chapters. Figure 46 shows the intentional elements and the intentional element associations modules. The Standard View is used in these two modules, which displays all the imported attributes. The figure shows a link from an intentional element to a contribution (id 106 in the second module).

GRL links are stored in a formal module to allow creating links with external objects in DOORS. In addition, having the links in a formal module allows for their simple visualization. It would have been possible to store links in a link module. However, the traceability analysis for such structure would have missed some attributes that have an influence on the model.

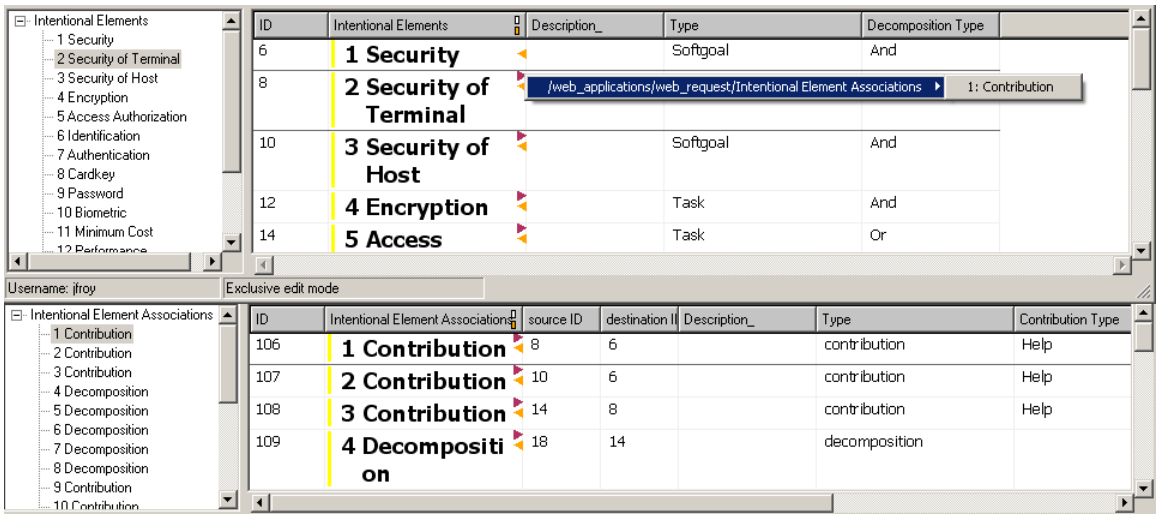


Figure 46. Intentional Elements and Intentional Element Associations Modules

GRL Diagrams:

```
bool grldiagram ( string modelID,
                  string modelName,
                  string graphFileName,
                  string title,
                  string theDescription )
```

Parameters:

- *modelID (String):* The identifier of the diagram.
- *modelName (String):* The name of the diagram.
- *graphFileName (String):* The diagram image file name.
- *title (String):* The diagram title.
- *theDescription (String):* The description of the element.

Description:

This function creates and updates a GRL diagram in the GRL diagrams module. The key attribute for the module is modelID, which uniquely identifies the object. This function contains a reference to an image file (bitmap). The graphFileName represents the name of this file, which shall be stored in the same folder as the executed DXL script. Other parameters correspond to attributes of the object.

```
bool actorRef ( string actorRefID,
                int fx,
                int fy,
                int width,
                int height,
                string referencedActor,
                string name,
                string parentActor )
```

Parameters:

- *actorRefID (String):* The identifier of the actor reference.
- *fx (int):* The x position of the actor reference in the diagram.
- *fy (int):* The y position of the actor reference in the diagram.
- *width (int):* The width of the actor reference in the diagram.
- *height (int):* The height of the actor reference in the diagram.
- *referencedActor (String):* The identifier of the actor definition.
- *name (String):* The name of the actor reference.
- *parentActor (String):* The identifier of the parent actor reference (if any).

Description:

This function creates and updates an actor reference in the GRL diagrams module. It is created as a sub-object of the latest created/updated GRL diagram object. The key attrib-

ute for the module is actorRefID, which uniquely identifies the object. Other parameters correspond to attributes of the object. The referencedActor is used to create a link to an actor definition (in the actors module). The parentActor attribute is used to create a link to the actor reference on which the object is bound (if any).

```
bool intentionalElementRef ( string refID,
                             int fx,
                             int fy,
                             string enclosingActor,
                             string defID,
                             string name,
                             string theDescription,
                             string priority,
                             string criticality)
```

Parameters:

- *refID (String):* The identifier of the intentional element reference.
- *fx (int):* The x position of the element reference in the diagram.
- *fy (int):* The y position of the element reference in the diagram.
- *enclosingActor (String):* The identifier of the parent actor reference (if any).
- *defID (String):* The identifier of the definition.
- *name (String):* The name of the intentional element.
- *theDescription (String):* The description of the intentional element.
- *priority (String):* The priority of the reference.
- *criticality (String):* The criticality of the reference.

Description:

This function creates and updates an intentional element reference in the GRL diagrams module. It is created as a sub-object of the latest created/updated GRL diagram object. The key attribute for the module is refID, which uniquely identifies the object. Other parameters correspond to attributes of the object. The defID is used to create a link to the intentional element definition (in intentional elements module) and the enclosingActor is used to create a link to the actor reference on which it is bound (if any).

```
bool belief ( string id,
              int fx,
              int fy,
              string enclosingActor,
              string linkElementId,
              string name,
              string theDescription,
              string author)
```

Parameters:

- *id (String):* The identifier of the belief.
- *fx (int):* The x position of the belief in the diagram.
- *fy (int):* The y position of the belief in the diagram.
- *enclosingActor (String):* The identifier of the parent actor reference (if any).
- *linkElementId (String):* The identifier of the intentional element on which the belief is linked (if any).
- *name (String):* The name of the belief.
- *theDescription (String):* The description of the belief.
- *author (String):* The author of the belief.

Description:

This function creates and updates a belief in the GRL diagrams module. It is created as a sub-object of the latest created/updated GRL diagram object. The key attribute for the module is id, which uniquely identifies the object. Other parameters correspond to attributes of the object. The enclosingActor is used to create a link to the actor reference on which it is bound (if any) and linkElementId to create link to the intentional element reference on which it is associate (if any).

Example:

The GRL diagrams module contains multiple object types. Each type has common and specific attributes. Using the views, it is possible to show only the attributes used by a specific object type.

Figure 47 shows the structure of the elements in a diagram. References and beliefs are a subset of a diagram. Thus, they are identified using a number under the diagram. In addition, internal links are created between the diagram elements and their parents (using

the *Refines* link module). The diagram objects also store the images in their main attributes.

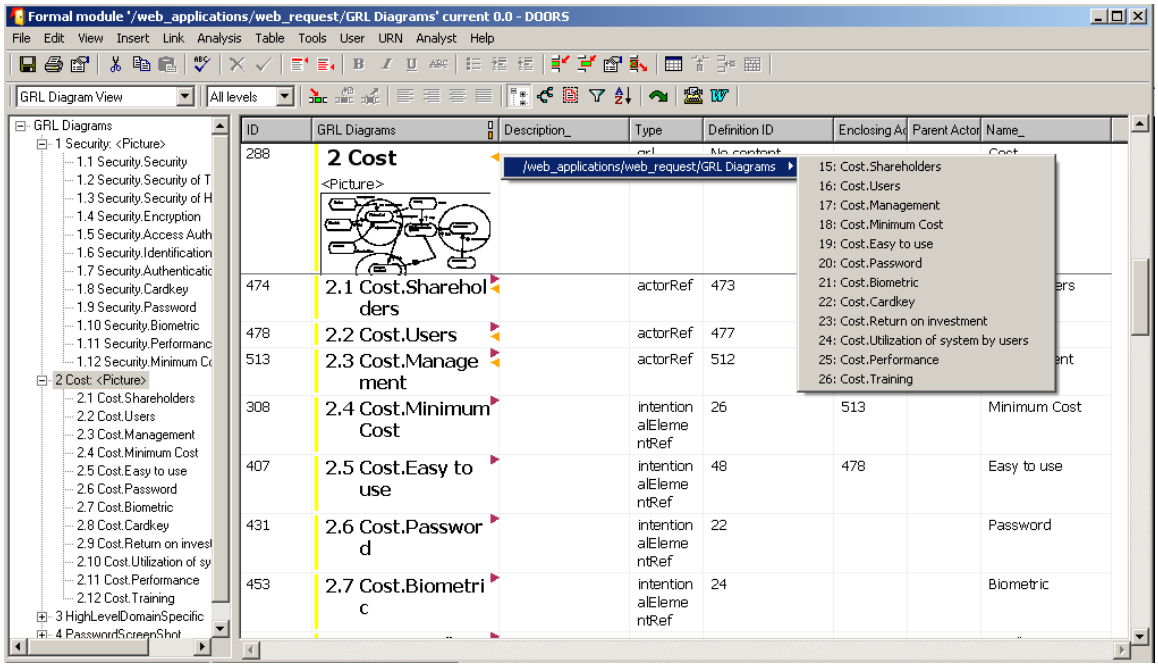


Figure 47. GRL Diagrams Module

GRL Strategies:

```
bool strategy ( string elementID,
                string elementName,
                string theDescription,
                string author )
```

Parameters:

- *elementID (String):* The identifier of the strategy.
- *elementName (String):* The name of the strategy.
- *theDescription (String):* The description of the strategy.
- *author (String):* The author of the strategy

Description:

This function creates and updates a strategy in the Strategies module. The key attribute for the module is elementID, which uniquely identifies the object. Other parameters correspond to attributes of the object.

bool ***evaluation*** (string name,
string value)

Parameters:

- *name (String):* The name of the intentional element.
- *value(String):* The value of the evaluation for the intentional element.

Description:

This function creates and updates an evaluation for the latest created/updated strategy. The name corresponds to an intentional element or actor id, which is set as an attribute. If the attribute does not exist, it is created. Then, the value parameter is set for this attribute, which corresponds to the evaluation.

bool ***defined*** (string name,
string value)

Parameters:

- *name (String):* The name of the intentional element.
- *value(String):* The value of the evaluation for the intentional element.

Description:

This function creates and updates a user-defined evaluation for the latest created/updated strategy. It is implemented as the evaluation function, but a star (*) is added at the end of the evaluation value (to distinguish user-defined evaluations from calculated evaluations in the module).

Example:

All the strategies from the Web application case study were exported to DOORS. Figure 48 shows the resulting formal module. Rows define the different strategies available in the model and columns correspond to identifiers of the elements used in the strategies (actor and intentional element definitions).

The Strategies module can be implemented using two alternatives: using strategies or using element ids as the objects. Using element ids has the advantage of allowing the creation of internal links between the elements and their definitions. However, the strategies option encapsulates the dynamic behaviour of the GRL model, which can be

linked to external elements. Thus, the implementation uses the strategies as objects, with elements ids as attributes.

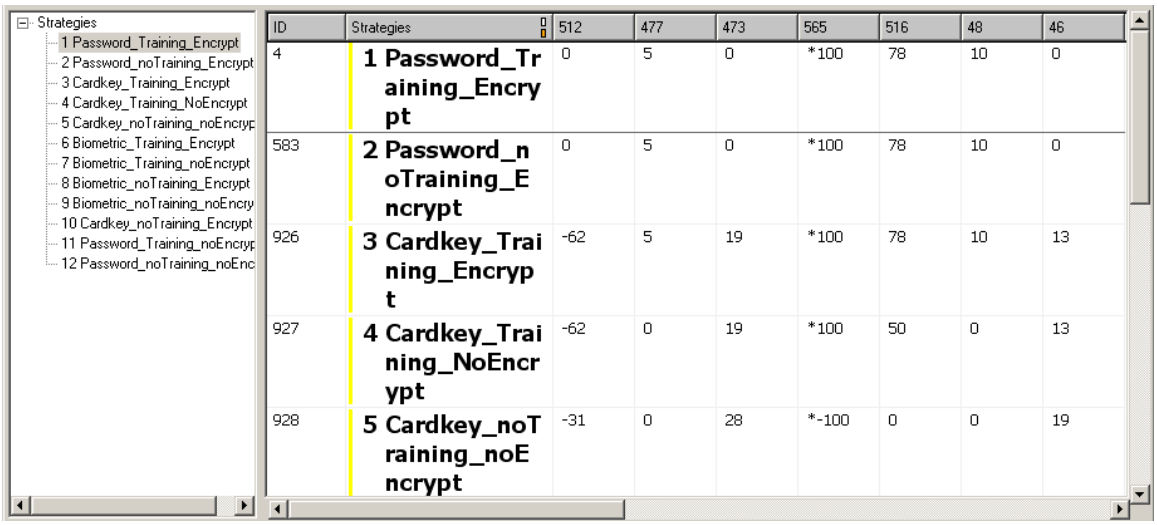


Figure 48. Strategies Module

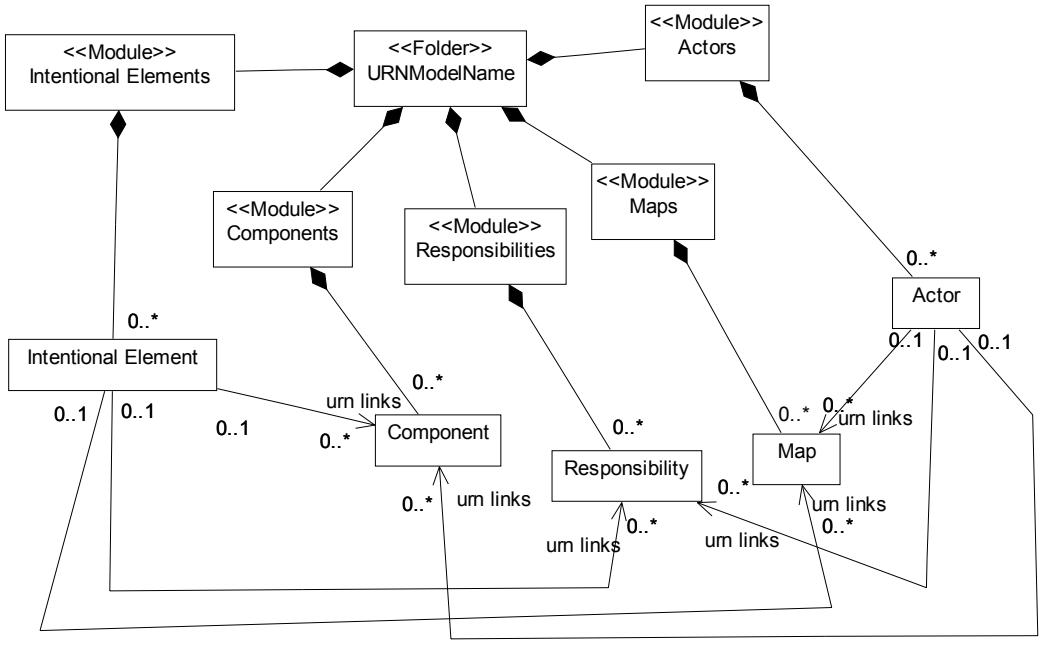


Figure 49. URN Links in DOORS

URN Links:

bool ***urnlink*** (string sourceID, string destinationID)

Parameters:

- *sourceID (String):* The identifier of the link source.
- *destinationID (String):* The identifier of the link destination.

Description:

This function creates and updates URN links from a source element to a destination element. These links are created in the urn links module (DOORS link module). The links are created from GRL elements to UCM elements, as supported in jUCMNav. The structure of URN links in DOORS is shown in Figure 49.

5.3 Using URN Models in DOORS

This section presents how to use imported URN models in DOORS. Linking URN models to external requirements is required to support parallel evolution of the URN model and of the requirements. The suggested strategy to create the links is presented. Then, a description of the updating mechanism is described, focusing on traceability analysis and synchronizations of URN and requirements.

5.3.1 Linking to DOORS

URN models and textual requirements are complementary artefacts. URN models are created using objectives, goals, and user requirements. The functional requirements guide the creation of the UCM sub-view while non-functional requirements help developing the GRL sub-view. However, URN models also help discovering lower-level requirements. In addition, the analysis mechanisms allow questioning the requirements. Thus, the development of URN models and requirements is an iterative process.

Importing URN in a RMS allows generating traceability links between the two types of artefacts, and managing the evolution of requirements and models. The preceding sections demonstrated how to import URN models into DOORS. Once the first ver-

sion of the model is imported, DOORS users need to create links between URN elements and external requirements, as discussed in Figure 15.

Typical DOORS requirements databases contain various formal modules, which represent requirements at various levels, such as business process requirements, user requirements, system requirements, and testing requirements. Traceability links are created between these formal requirement modules.

We suggest using the URN models as a supplement to the requirements by inserting the models between these formal modules. Instead of linking requirements types directly, URN model are used to fill the gap between their formal modules. They are documenting the rationales behind the requirements and the thinking process that results in the lower level requirements. Figure 50 shows how the links between requirement types are created. For example, links from *System Requirements* and *Business Process Requirements* use the *Business Process URN Model* to complete the traceability links.

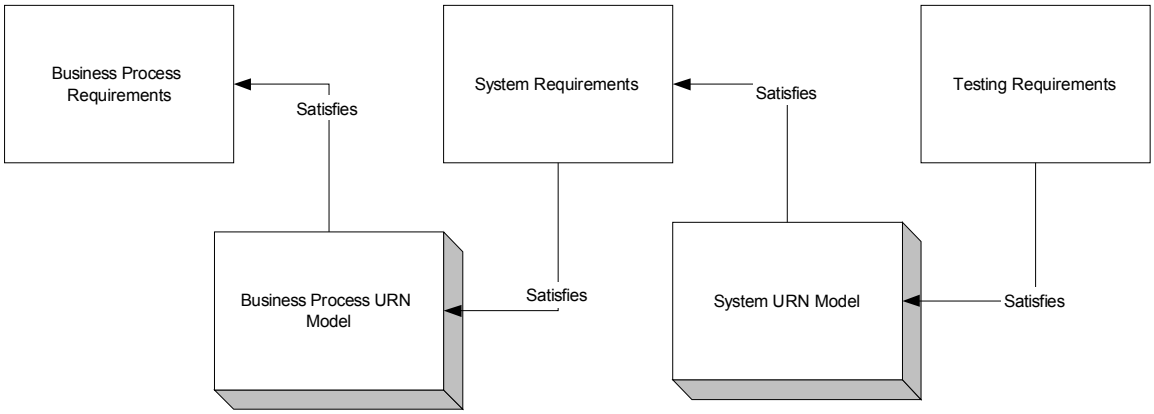


Figure 50. Typical External URN Links

Links can be created between elements in any direction. However, to support traceability analysis, it is required to standardize the link direction. Since the internal links in URN are created bottom-up, from lower-level to higher-level elements, external links should follow the same standard. Adopting this structure allows DOORS users to use the default *suspect links* mechanism. A suspect link is a flag added to a DOORS link in order to indicate that one of the link members has changed. Then, requirement engineers can evaluate the impact of the changes on the other end of the link, and modify the linked object if this is relevant. Thus, if linked requirements or URN elements change, DOORS users are informed, allowing them to manage the evolution of the requirements and URN models.

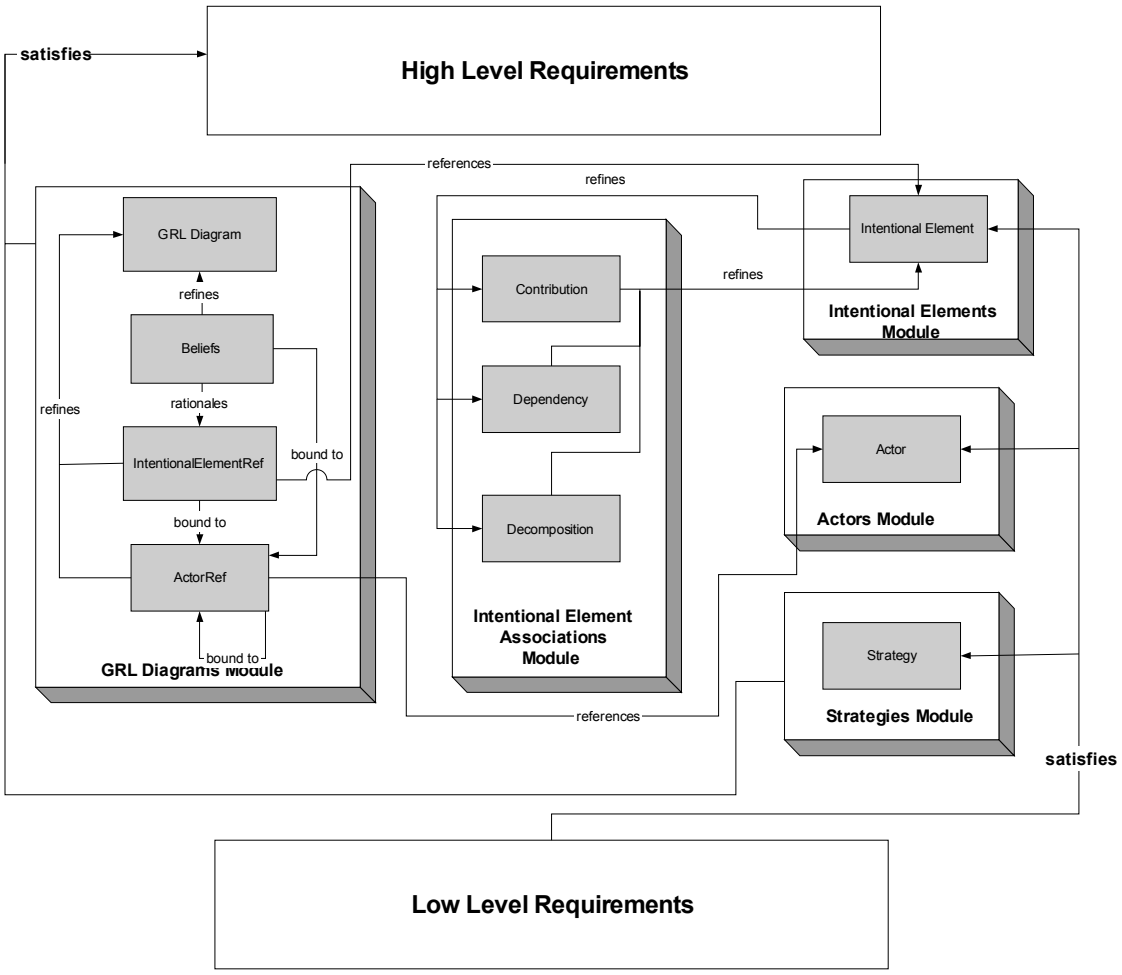


Figure 51. External and Internal Links for GRL in DOORS

Typical links between the GRL modules and external requirements are represented in Figure 51. They are developed using the same strategy as for UCM models [27]. Links from low-level requirements can target Strategies, Actors or Intentional Elements modules. Definitions and strategies are elements that have an influence on requirements. For links from GRL to higher-level requirements, they can be created from *Strategies* or GRL *Diagrams* modules (from *GRLDiagram*s, *IntentionalElementRef*s, *ActorRef*s, or *Belief*s). Links to other elements can be created, but these elements can be modified frequently and can often generate suspect links that do not require changes.

Suspect links can also be used when linked requirements evolve. DOORS users can inspect the suspect links and report URN elements that need to be revisited by the URN modeller.

5.3.2 Model Synchronization

To import a new version of a URN model in DOORS, the URN modeller must generate a new DXL script using the jUCMNav exporter. It is required that the URN model name remains the same as the initial model name. This ensures that the model is updated in DOORS, instead of creating new modules.

During initialization of the DXL scripts, the URN model is pre-processed, preparing the module to receive the updates. First, all the internal links in the model are removed. Then, all URN elements in DOORS have their *deleted* attribute set to true.

Once the initialization is finished, the process executes the calls from the new DXL script. For each element in the script, the process searches the object list, based on object ids. If a corresponding object is found, attributes are updated and the *deleted* attribute is set to false. For elements that are not found in the list, they are created and are added to the object list. When elements are updated, some of their attributes are not relevant to the external requirements. For example, the position of elements in the diagram shall not trigger *suspect links*. These attributes have a flag to specify that they should not affect the linked elements.

When all the elements are updated, the process looks at the objects that still have their *deleted* attribute set to true. First, it tries to delete these objects. However, DOORS does not allow deleting an object that is a destination element of a link. It is the user responsibility to look at these objects and evaluate the impact on the external requirements. Then, they should delete the links and the objects. To assist users in this task, the *Deleted View* allows seeing all the elements that should be deleted by the user. Other views are also available to support the users in the synchronization process, such as the *New View,* which shows all the new elements added in the model.

The script uses another mechanism to update the GRL Strategies module. Since intentional elements are attributes of the objects, using the intentional element name in the strategy would have generated suspect link each time a name changes in the model. To solve this problem, the id is used to describe the intentional elements and actors in this module. When an update is made, if the id of an element is not available in the attributes, a new attribute is created.

The last step of the update process consists of recreating the internal links in the URN model. This step does not affect the external requirement links because link modifications are considered by the system as minor updates.

5.4 Chapter Summary

This chapter presented how URN models can be linked to external requirements using a common RMS. This allows developing complete requirements that also document the rationale for these requirements. Since requirements can evolve over time, the traceability mechanism presented allows triggering events when URN models or external requirements need to be revisited.

The process for importing URN model is composed of three steps. First, as presented in Section 5.1, the URN modeller must generate a DXL script from the model. A utility, the DOORS exporter, is available in jUCMNav to automate this task. Then, as discussed in Section 5.2, the DOORS user must execute the script. The latter invokes functions of a DXL API that creates the required modules, objects, and links. Once the model is imported, DOORS users can create links between the model and external requirements. These links are the main element used for traceability analysis. As detailed in Section 5.3, the model/requirements evolution can be managed using *suspect links*, in a way similar to what was proposed by Jiang *et al*. [27][37].

The next chapter will demonstrate how to model requirements with jUCMNav and DOORS, using a more complex case study: a Web credit card gateway.

Chapter 6 Case Study: Credit Card Gateway

This chapter presents a case study that uses the tools and approaches described previously. The case study is a Web credit card gateway, which contains multiple requirements that sometimes conflict, such as security and cost. To model and analyze the requirements, a URN model is developed in jUCMNav, and the analysis mechanisms are used. Finally, the model is exported to DOORS.

The first section introduces the development of the URN model based on four architectures considered for this system. It describes the high-level functional and non-functional requirements for the system. In section 6.2, we add URN links between elements in the model, which will show that the model requires further refinement. This refinement will be realized using a small GRL catalogue. Then, in section 6.3, the new jUCMNav analysis features are used to analyze requirements and determine the best architectural solution for this case study. The model is also exported to DOORS and linked to external requirements in section 6.4.

6.1 Modelling Using URN

Despites a large number of e-business Web sites, offering a secure and robust architecture for credit card payment remains a problem. In this situation, merchants use third party services such as credit-card gateways, which are services acting as middle-men between merchants and a bank in order to manage the transactions securely. Credit-card gateways allow merchants to develop their e-business sites more rapidly, without having to deal with requirements for credit card processing. However, for this type of service to be successful, it shall satisfy the concerns of a large number of stakeholders, such as merchants, customers, and banks. As suggested by Lamsweerde [31], goal models can guide the selection of a suitable architecture while taking such concerns into account.

6.1.1 Customers-Merchants Modelling

The requirements for a credit card processing service are driven by the customers-merchants collaborations. Figure 52 shows the buying process between customers and merchants. This process considers only the situation where the customer has selected product(s) to buy. Once the merchant requests the payment, the customer enters the payment information, which corresponds to the payment method (*Furnish payment information* responsibility). If the payment method is credit card, then the merchant uses the credit card gateway to process the payment, which is modeled in a dynamic stub. Other payment methods are not considered in this model but could be added to the *Process Payment* stub.

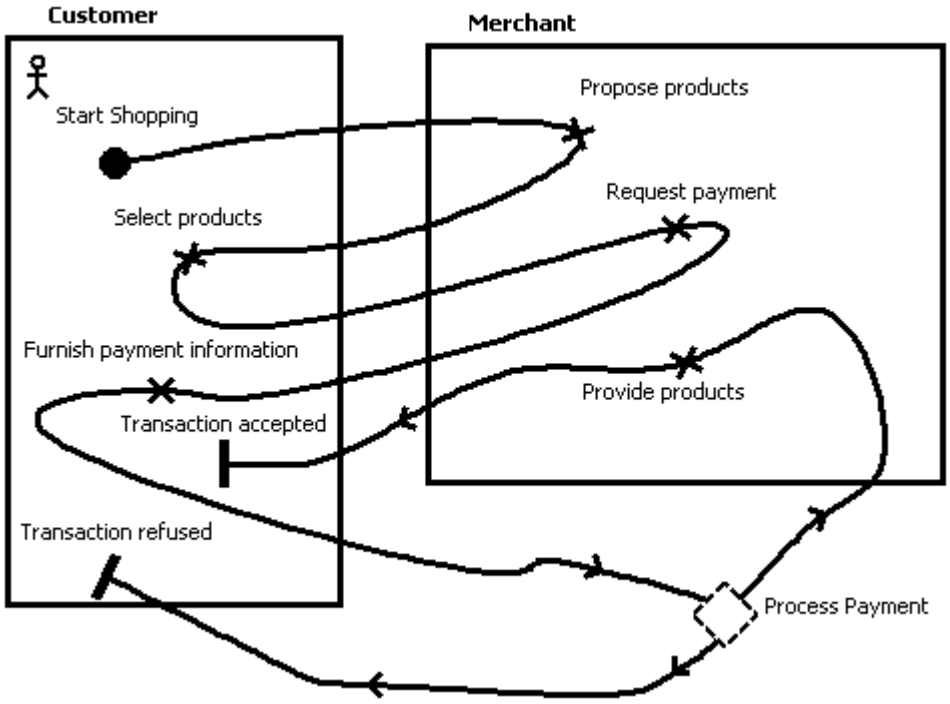


Figure 52. Buying Process between Customer and Merchant

A transaction happens between a customer and a merchant to satisfy their goals. The main goal of the customer is to receive the desired products. However, this goal is satisfied only if the merchant provides these products. This relation is modeled as a three-element dependency, with the customer depending on *Products* resources, which are provided by the merchant (Figure 53). A similar dependency is created for the payment. The

goal of the merchant is to receive the payment. He depends on the customer to provide the *Payment* resource.

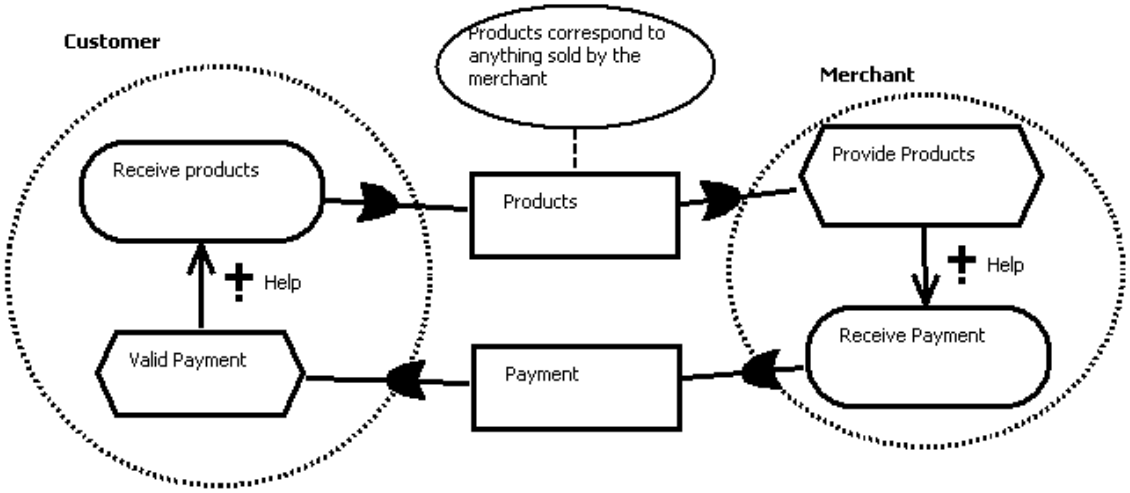


Figure 53. Dependencies between Merchants and Customers

6.1.2 Potential High-Level Architectures

In this case study, four alternative architectures are compared. The UCM model developed for these architectures represents collaborations between three main components: Customer, Merchant and Payment Gateway. In addition, each of the architecture uses the same submap to represent the credit card processing at the bank (Figure 54).

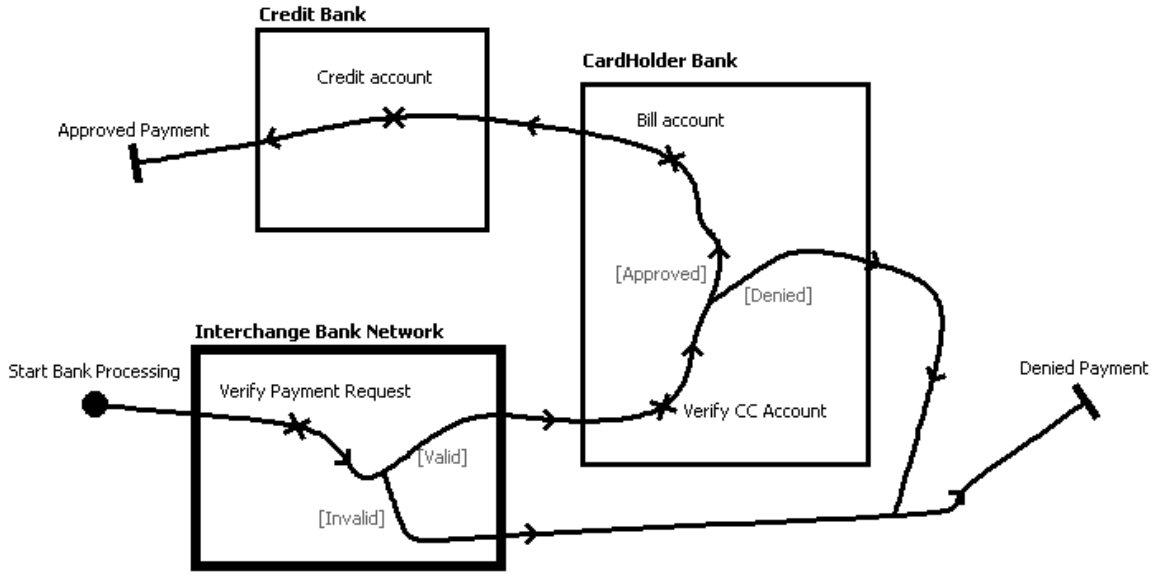


Figure 54. UCM of the Bank Credit Card Processing

The bank processing map uses three components. First, the *Interchange Bank Network* is responsible for verifying the payment request, and forwarding the request to the card-holder bank if it is valid. Then, the *CardHolder Bank* verifies the credit card account. If this account fills all the requirements to accept the payment, it is billed and the request is forwarded to the *Credit Bank*. This component is responsible to credit the paid account, which can be the account of the merchant or the account of the payment gateway, depending on the architecture.

Standard Payment Processing

The standard payment processing architecture is the simplest architecture for this type of service. As shown in Figure 55, the payment form is provided to the user by the merchant. Then, the user enters its credit card information (name, number, expiration date), and sends the information to the merchant. The merchant adds account and payment information, and forwards the request to the payment gateway. The gateway verifies the payment request, and sends it to banks (*Bank Processing* stub) if it is valid.

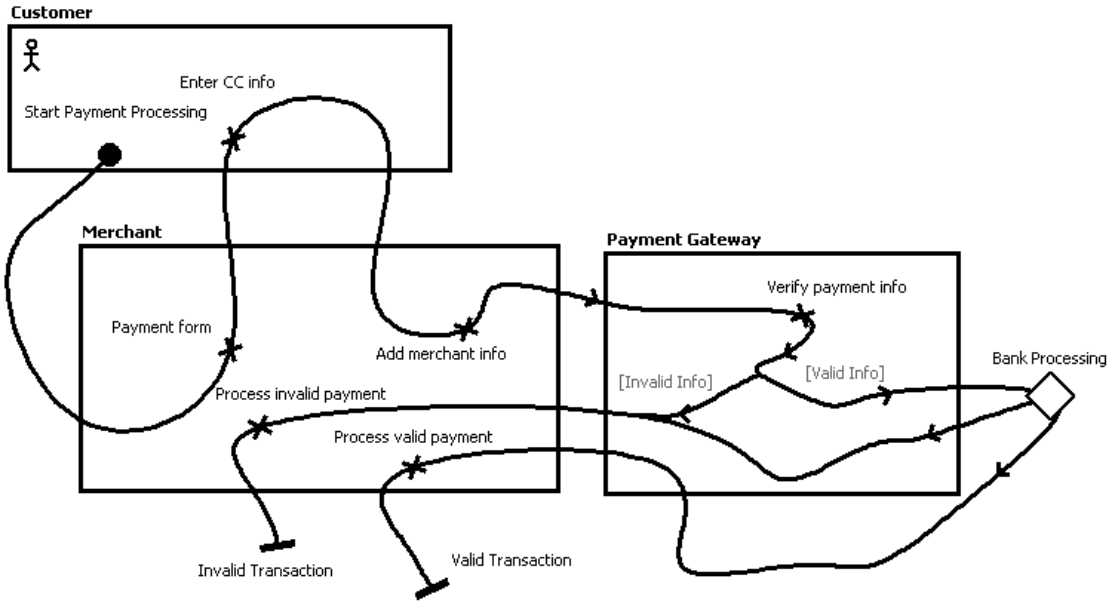


Figure 55. Standard Payment Processing UCM

Gateway to Customer Payment Processing

This architecture differs from the standard payment processing by moving two responsibilities to the payment gateway: *Payment form* and *Verify payment info*. The transaction starts with the merchant that add it information to the payment request, which is forward

to the payment gateway (Figure 56). In this architecture, only the payment gateway accesses the credit card information. Limiting access to this critical data reduce security risks of the transactions.

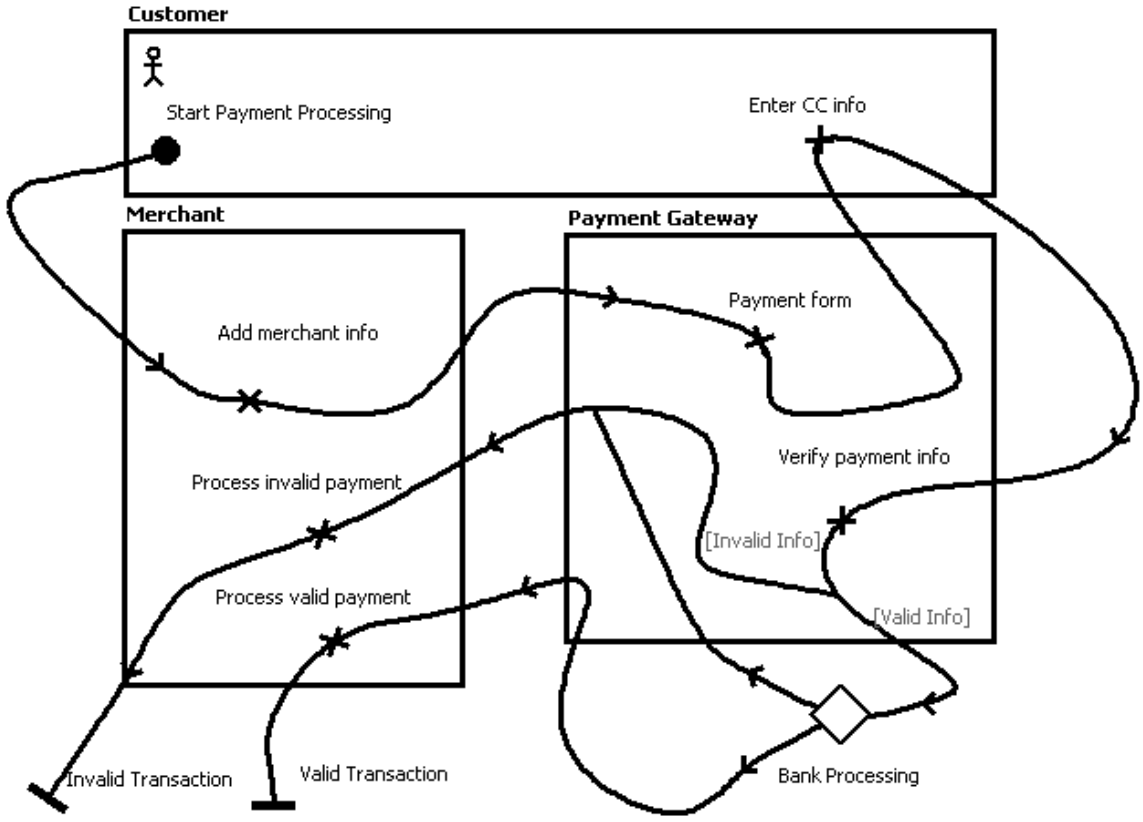


Figure 56. Gateway to Customer Payment Processing UCM

Third Party Payment Processing

In this architecture, customer and merchant shall have registered to the gateway services prior to the transaction. Once a payment request is sent by the merchant, the customer is redirected to the payment gateway Website to process the request. As shown in Figure 57, the user logs in its account, and the gateway manages the access to the credit card. After the bank has processed the transaction, messages are sent to the customer and the merchant to inform them of the result of the transaction. This is the approach used by services such as Paypal [44].

3D Secure Payment Processing

The 3D Secure [57] is a standard developed by credit card associations (including VISA and Mastercard) to support secure transactions and to minimize the requirements placed

on the merchant. This approach requires that the cardholder registers with the system prior to using his credit card. During the transaction, the merchant has the responsibility of providing the payment form to the customer, and has access to the credit card information. However, for a transaction to be valid, the customer needs to enter his password. The merchant does not have access to this password, as shown in Figure 58.

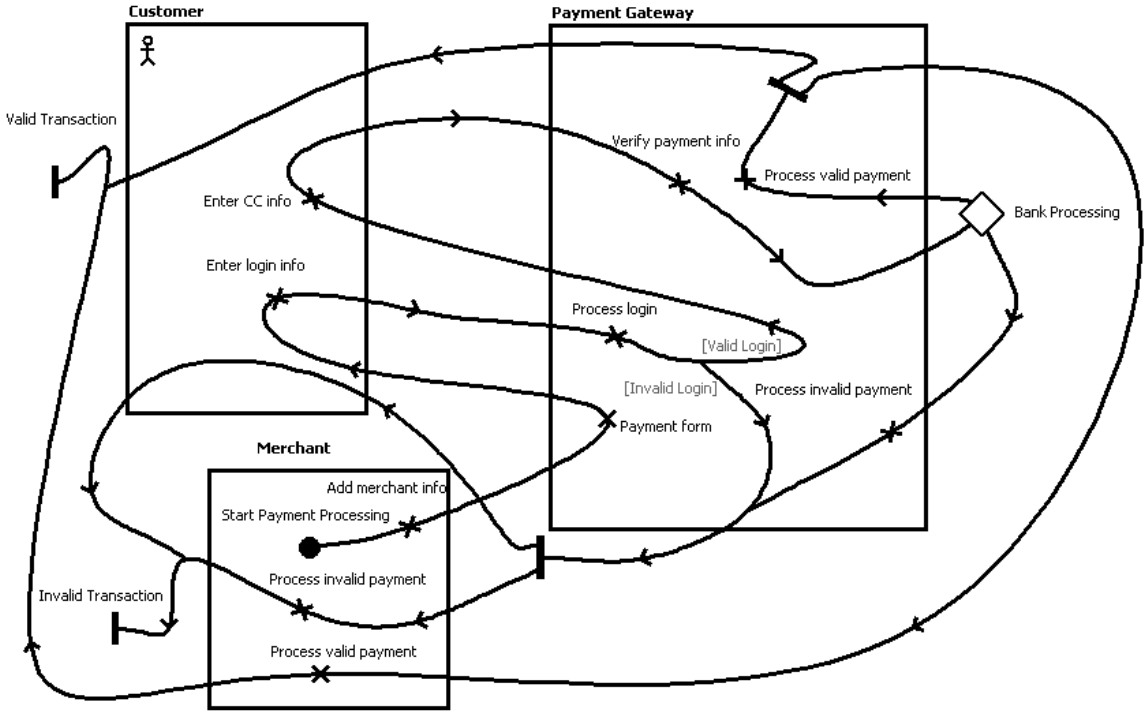


Figure 57. Third Party Payment Processing UCM

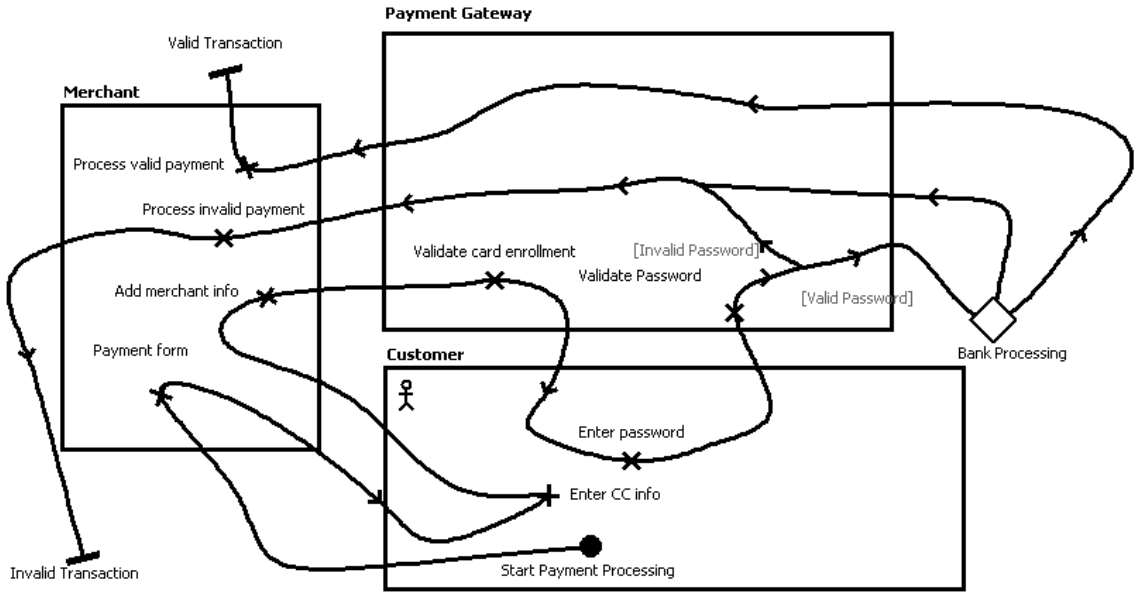


Figure 58. 3D Payment Processing UCM

6.1.3 GRL Model

The GRL model for this case study captures the concerns of the stakeholders involved in the system. As shown in Figure 59, cardholder is modeled as a sub-actor of the customer in order to represent that the cardholder is a customer with additional concerns. Even if the customer and the cardholder are habitually the same person, the customer is concerned by the products whereas the cardholder is concerned with the payment and security. If the cardholder can achieve secure payments, this influences its trust of the merchant (*Some Positive)*. Buying the merchant product is a task which is affected by the satisfaction of the goals of both the customer and the cardholder. This intentional element is an example of a task that can have a weakly satisfied or weakly denied evaluation.

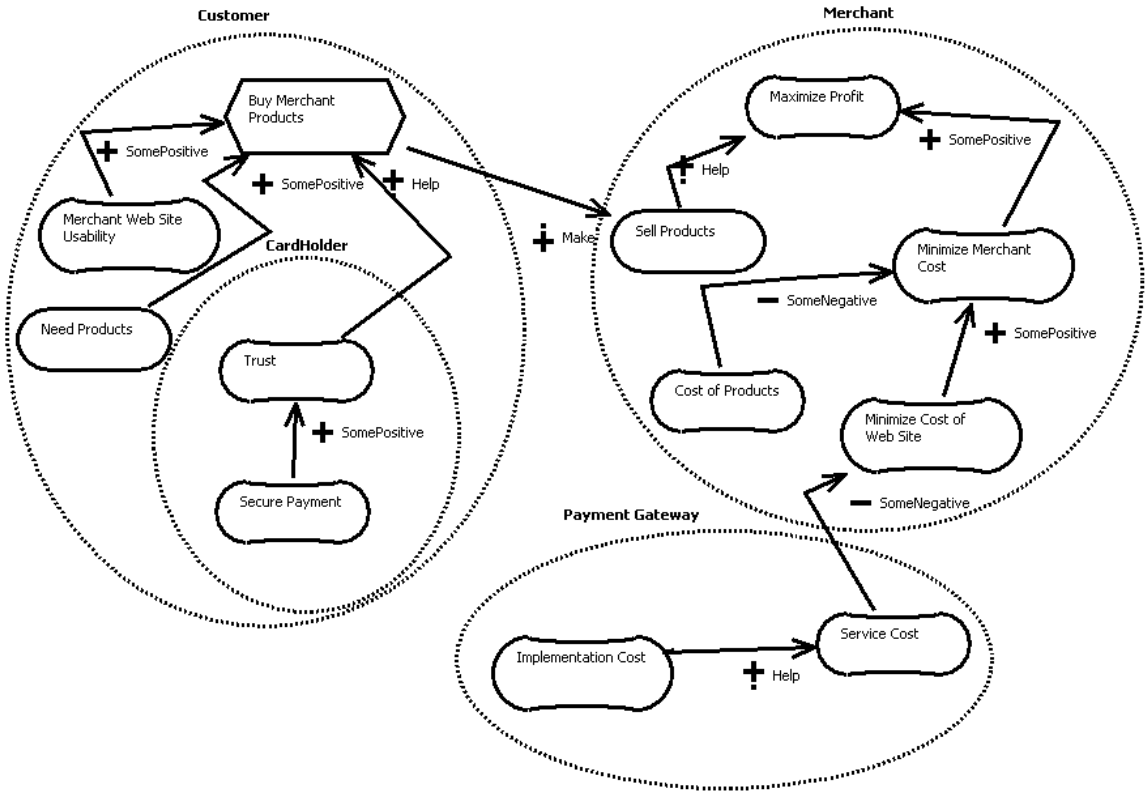


Figure 59. High-Level Goal Model

Buy Merchant Products highly contributes to the *Sell Products* goal, which in turn helps maximize the merchant profits. In addition, minimizing the merchant cost has a positive impact on the profit. In this model, merchant cost is affected by two softgoals (*Cost of Products* and *Minimize Cost of Web Site)*. However, other elements impact the merchant cost, which are not considered in this case study. The cost of the payment gateway has an impact on the cost of the merchant's Web site. In addition, this concern is bound to the payment gateway, because highly expensive services will not be adopted by the merchants. To be able to minimize the service cost, payment gateway shall minimize the system implementation cost.

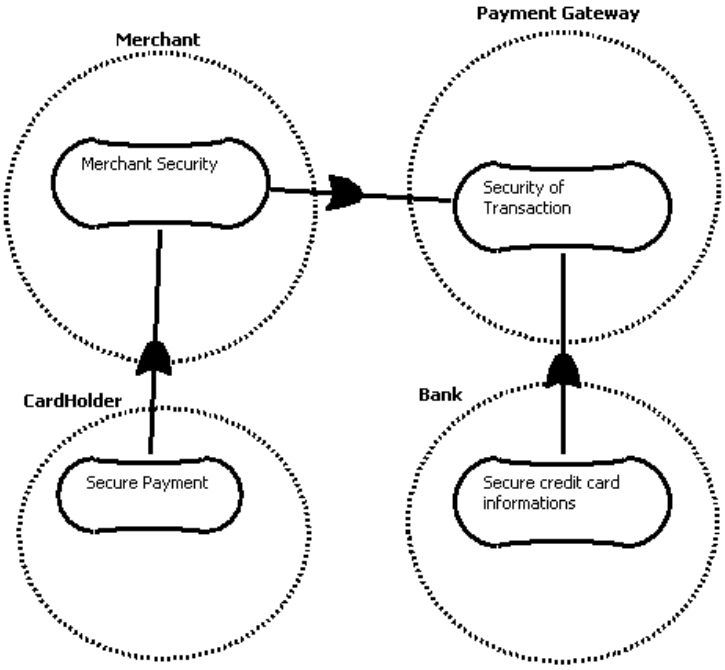


Figure 60. Security Dependencies

The high-level goal model introduces a *Secure Payment* softgoal, which is a critical concern for the cardholder. In the context of credit card transactions, if security is decomposed into security goals for each actor involved in the system, then the *Secure Payment* softgoal can never have a satisfaction value higher than the lowest value of the component. Thus, it depends on the security of other actors. This is modeled in Figure 60, where *Security of Transaction,* bound to the payment gateway, influences the security of all other security softgoals.

The implementation cost, a requirement for the payment gateway, is affected by the architecture. Architectures are modeled using GRL tasks (see Figure 61) that affect the *Minimize Implementation Cost* softgoal in different ways.

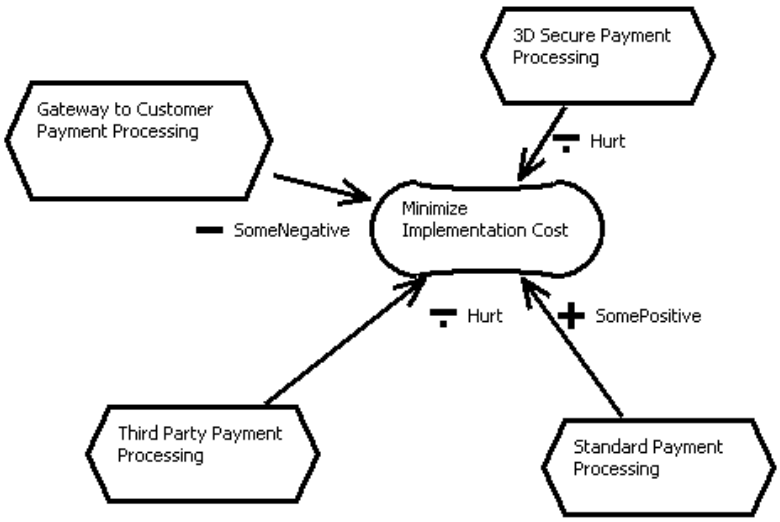


Figure 61. Implementation Cost Model

The URN diagrams shown here were developed using the new jUCMNav. Using additional features of our tool, it is now possible to refine the model and better reflect the requirements.

6.2 Evolving the Credit Card Gateway Model

In this section, to support the integration of both URN sub-notations, URN links are added to the model. These links enable the analysis of the model and the discovery of locations where the model shall be further refined. Then, using a GRL catalogue, new intentional elements are added and integrated to the URN model.

6.2.1 Creating URN Links

Adding URN links allows supporting traceability between UCM and GRL elements. Then, when the model evolves, it becomes possible to evaluate the impact of changes on linked elements. The URN links can be developed at the same time as the model.

In the model, links are added between actors and components. The actors in GRL correspond to stakeholders involved in the process, often shown as components in UCMs. Thus, links are created between actors *Customer*, *Merchant* and *Payment Gateway* and

UCM components *Customer*, *Merchant,* and *Payment Gateway*, respectively. Note that in the UCM model, no distinction is made between customer and cardholder. In this situation, we used the parent actor of cardholder (customer) to create the links. Links are also created between the *Bank* actor and the corresponding UCM components (*Interchange Bank Network, CardHolder Bank* and *Credit Bank*).

The architecture tasks can also be linked to their corresponding plug-in maps in the UCM view. However, no links can be made at this point between intentional elements and responsibilities. Some of the responsibilities have an influence on the satisfaction of intentional elements. Therefore, further refinement of the GRL model is required.

6.2.2 Adding a Secure Transaction Catalogue

GRL catalogues allow reusing models previously developed. In the credit card gateway case study, we are using a small catalogue to model transaction security. This catalogue, which can be used in any context that has transactions, describes high-level softgoals that should be satisfied to achieve security of transactions. Figure 62 shows the catalogue, where the main concern is to achieve secure transactions by satisfying integrity and non-repudiation of the information. Integrity corresponds to the quality of transactions where information cannot be altered by an unauthorized party without being detected. Non-repudiation of transaction ensures that the sender and receiver involved are the parties they claim to be. Authentication is a softgoal that helps achieving non-repudiation. Finally, confidentiality influences positively the security of transactions.

When the catalogue is imported in the URN model, a new GRL diagram is created with the imported elements. To integrate it with the model, intentional elements that are the same in the catalogue and the model should use the same element definition. During the import process, when the name of an imported element is the same name as one of the elements in the model (name clash), a suffix is added to the name (i.e. *Security of Transaction* is renamed *Security of Transaction2*). In the case study, we change the intentional element reference of *Security of Transaction* to the definition used in Figure 60.

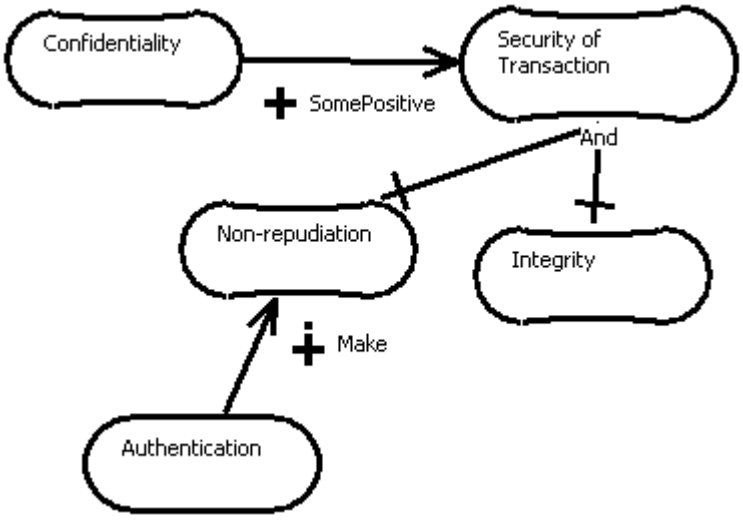


Figure 62. GRL Model of the Security of Transaction Catalogue

Once the catalogue is integrated with the model, the security model is refined to adapt it to the context of the credit card gateway (Figure 63). If the main security goal is satisfied (on which depend the security of cardholders, merchants, and banks, as described in Figure 60), this would help satisfying three other goals: *Receive Payment*, *Receive Products* and *Trust*. These associations are modeled as correlations because they are side-effects.

The *Authentication* goal is decomposable for each party involved in the transaction, i.e. cardholder and merchant. The authentication of the parties is hard to satisfy. However, using certificates helps authenticate the actors. In addition, the architectures that are using a password to identify cardholders (3D Secure and Third Party) help authenticate these cardholders. *Integrity* can also be decomposed into *Payment Data Integrity* and *Credit Card Information Integrity*. In this case study, the only method proposed to achieve integrity is encryption (modeled as a task). Finally, some of the architectures allow merchants to access credit card information. This is a security risk affecting the credit card information integrity and confidentiality (*Some Negative* for *Credit Card Information Integrity* and *Hurt* for *Confidentiality*).

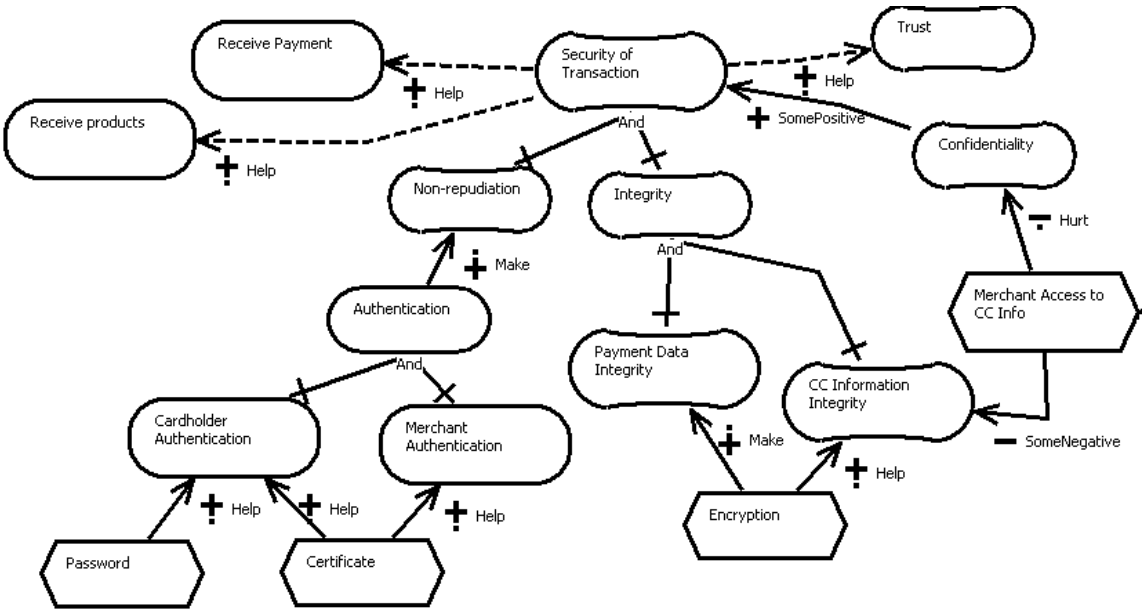


Figure 63. Security of Transaction Model

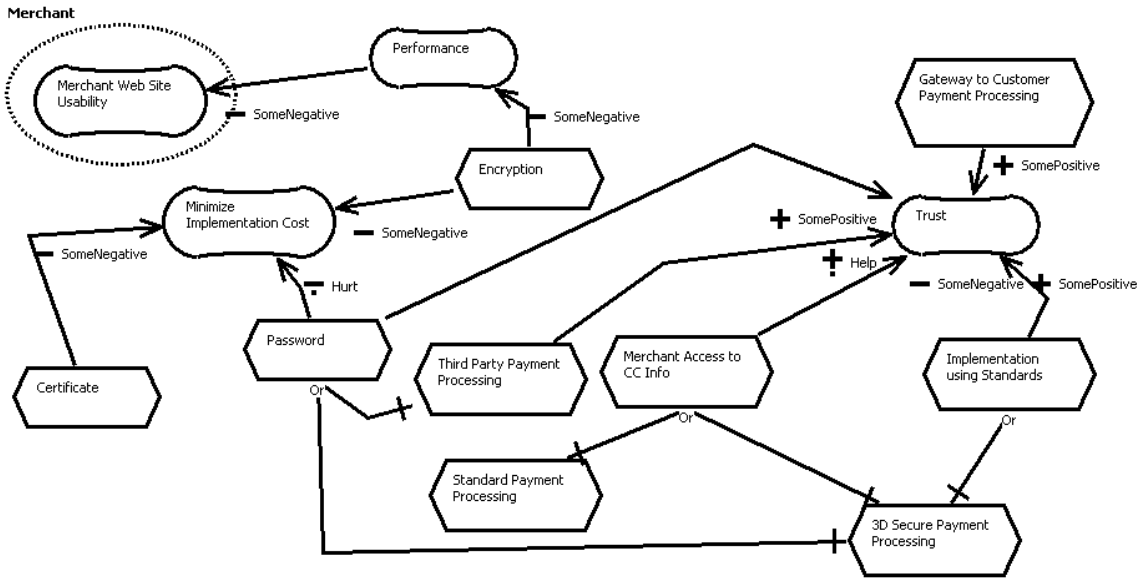


Figure 64. GRL Architectural Model

Once the security model is refined, it is necessary to associate the new tasks created with the architectural tasks. This is realized in the architectural model of Figure 64. Additional contributions on *Trust* and *Performance* are also created in this diagram.

Finally, it is possible to develop new URN links using the tasks added. Intentional elements such as *Password* correspond to responsibilities in the UCM model. A list of all URN links created for this model is shown in Table 7.

GRL Element	UCM Element	Link Type
3D Secure Payment Processing	3D Secure Payment Processing Map	Intentional Element (Task) → Map
Bank	Interchange Bank Network	Actor → Component
Bank	CardHolder Bank	Actor → Component
Bank	Credit Bank	Actor → Component
Customer	Customer	Actor → Component
Gateway to Customer Payment Processing	Gateway to Customer Payment Processing Map	Intentional Element (Task) → Map
Merchant	Merchant	Actor → Component
Password	Enter Password	Intentional Element (Task) → Responsibility
Password	Validate Password	Intentional Element (Task) → Responsibility
Payment Gateway	Payment Gateway	Actor → Component
Standard Payment Processing	Standard Payment Processing Map	Intentional Element (Task) → Map
Third Party Payment Processing	Third Party Payment Processing Map	Intentional Element (Task) → Map

Table 7 List of URN Links in the Credit Card Gateway Model

6.3 Analyzing the Model

Once the model is developed, the analysis mechanisms added to jUCMNav can be used to evaluate the impact of the four alternative architectures on the requirements. First, we develop GRL strategies for each architecture. Then, the actor evaluation mechanism is used to find the solution that maximizes the satisfaction level of the actors.

6.3.1 Evaluation of Intentional Elements

To achieve a useful comparison of the architectures, it is necessary to determine the variation points in the model. These variation points are intentional elements, usually tasks, which have user-defined evaluations in the GRL strategies. In this case study, we are comparing four architectures, which are the elements that should have user-defined evaluations. In addition, these architectures are mutually exclusives. The impact of encryption and certificate on the requirements is also interesting to evaluate. The usage of these elements should be combined with the architectures.

The strategies are structured using groups for each of the architectures. Strategies with certificate and encryption and strategies without certificate and encryption are created. Table 8 shows the impact of strategies on the high-level intentional elements. The result of the strategies does not allow making a decision on which architecture to use. Some of the intentional element evaluations are opposite. For example, if we want to minimize the implementation cost, the standard payment architecture with encryption and certificate is the best solution but it is the worst solution for security of transactions. Therefore, further analysis of the model is required.

6.3.2 Evaluation of Actors

To maximize the actors' satisfaction levels, it is required to add criticality and priority to the intentional elements bound to actors. By default, these values are set to *none*, which result in satisfaction labels of 0 for actors.

Table 9 shows the priorities and criticalities assigned to the intentional element references (note that the table shows only references that have an assigned priority or criticality). Elements that have multiple references can have different priorities and criticalities for their actors. For instance, the *Merchant Web Site Usability* softgoal is bound to *Customer* (low priority and no criticality) and to *Merchant* (medium priority and medium criticality).

Intentional Elements	**3D With Encryption/Certificate**	**3D Without Encryption/Certificate**	**Gateway to Customer With Encryption/Certificate**	**Gateway to Customer Without Encryption/Certificate**	**Standard With Encryp-tion/Certificate**	**Standard Without Encryption/Certificate**	**Third Party With Encryption/Certificate**	**Third Party Without Encryption/Certificate**
Receive Products	33	27	38	0	33	21	38	0
Receive Payment	33	27	38	0	33	21	38	0
Security of Transaction	31	6	50	0	31	-19	50	0
Maximize Profit (Merchant)	58	61	61	59	60	58	62	60
Minimize Imple-mentation Cost	-90	-90	-75	-25	-25	25	-90	-90

Table 8 Impact of GRL Strategies on High-Level Goals

Intentional Element	Actor	Priority	Criticality
Maximize Profit	Merchant	High	High
Merchant Web Site Usability	Customer	Low	None
Merchant Web Site Usability	Merchant	Medium	Medium
Minimize Implementation Cost	Payment Gateway	Medium	None
Receive Payment	Merchant	High	High
Receive Products	Customer	High	High
Security of Transaction	Payment Gateway	High	High
Sell Products	Merchant	High	Low
Trust	CardHolder	Medium	High

Table 9 Priority and Criticality of Intentional Elements

Actors	3D With Encryption/Certificate	3D Without Encryption/Certificate	Gateway to Customer With Encryption/Certificate	Gateway to Customer Without Encryption/Certificate	Standard With Encryption/Certificate	Standard Without Encryption/Certificate	Third Party With Encryption/Certificate	Third Party Without Encryption/Certificate
CardHolder	72	65	78	31	10	7	100	93
Customer	31	25	36	0	31	21	36	0
Merchant	53	53	57	41	53	48	57	43
Payment Gateway	1	-24	25	-8	22	-10	20	-30

Table 10 Impact of GRL Strategies on Actors

Using the priority and criticality for intentional element references bound to actors, actor satisfaction levels are calculated. Table 10 shows the result for each strategy. Based on this evaluation, two architectures generate highly positive evaluations for each actor: *Gateway to Customer* and *Third Party* payment processing architecture (both with encryption and certificate). However, even if cardholder is fully satisfied with the third party architecture (evaluation of 100), the payment gateway is considered the actor with the highest importance because this is the actor representing the system to be developed. If its concerns are not satisfied, then there is no reason to develop the system. Hence, we select the Gateway to Customer architecture and preserve the model with strategies to document the rationale behind this major design decision.

6.4 Managing Requirements in DOORS

In this section, the URN model is imported into DOORS. Then, links to external objects are created. Using these external objects and links, modifications to the URN model are performed and the latter is re-imported into DOORS. Finally, we describe the impact of the modifications on the DOORS database.

6.4.1 Importing the Initial URN Model

Once the URN model is stable, it is imported into DOORS to link it with the external requirements. Importing the model in DOORS creates a new folder with the name of the URN model. In this folder, all the formal and link modules discussed in chapter 5 are created.

For this case study, two external formal modules are created in DOORS: User Requirements and System Requirements. These two modules contain requirements objects at a higher level for user requirements and at a lower level for system requirements. In addition, our focus is on the development of requirements that are linked to the GRL model, and the objects in these two modules represent only a small subset of the requirements for this system. For more information on the development of links with UCM models, see [27].

In the User Requirements module (Table 11), five textual objects are created to illustrate the capabilities of the tool. Each of these objects is a high-level requirement that should be satisfied by the credit card gateway system. Since these are high-level requirements, the links should be created from the URN model elements to these objects. In this case, all the links are coming from the GRL Diagrams module.

User Requirements Formal Module		
ID	Name	Link From GRL Diagrams Module
1	The cost of the system shall be minimal	Cost
2	Security of each sub-systems depends on the security of the payment gateway	Security Dependencies
3	The system shall validate the payment	High Level Dependencies
4	The payment gateway shall be trustable by the users	High Level Goal, Architectural Model
5	The system shall secure the transactions	Security Model

Table 11 DOORS User Requirements Formal Module

The same approach is used for the System Requirements module (Table 12). The links in this module are from its objects to the URN elements. We create links to three types of elements in URN: actor definitions, intentional element definitions, and GRL strategies.

System Requirements Formal Module		
ID	Name	Link To
1	The system shall minimize the cost of using the service for the merchant	- Merchant (Actor) - Minimize Cost of Web Site (Element)
2	The system architecture shall not allow merchants to access credit card numbers	- Merchant (Actor) - Merchant Access to CC Info (Element)
3	The credit card gateway service cost shall be lower than cost for the merchant to implement a payment system.	- Payment Gateway (Actor) - Minimize Service Cost (Element)
4	The credit card processing shall have good performance	- Payment Gateway (Actor) - Performance (Element)
5	The system should not affect the usability of the merchant Web site	- Merchant (Actor) - Merchant Web Site Usability (Element)
6	The credit card transaction shall be secure	- Gateway to Customer With Encryption /Certificate (Strategy)
6.1	The system shall use certificate	- Certificate (Element)
6.2	The system shall use encryption	- Encryption (Element)
6.3	The system shall manage the data to ensure confidentiality	- Confidentiality (Element)
6.4	The system shall use authentication methods	- Authentication (Element)

Table 12 DOORS System Requirements Formal Module

6.4.2 Updating a URN Model in DOORS

Using the links developed in the previous section, we modify the URN model in jUCM-Nav to evaluate the impact of each type of modification on the DOORS objects. The modifications that have an impact on the higher-level objects are adding, modifying and deleting GRL diagrams. The modifications that have an impact on the lower-level ele-

ments are adding, modifying and deleting actors, intentional elements, and strategies. The purpose of these updates is to test that all combinations are supported correctly in our tool.

GRL Diagrams

Description of the changes:

- Delete diagram Cost
- Add architectural tasks and link references to Minimize Implementation Cost in High Level Goals diagram
- Add new diagram calls Usability who has references to Merchant Web Site Usability, Service Usability softgoals, architectural tasks and new contributions.

DOORS Views:

- New intentional element references in *High Level Goal* diagram are displayed in the *New Object* view. These changes are not generating suspect links because only one link has been defined from the diagram object. Changes on elements in the diagram are not considered significant changes (significant changes correspond to attribute modifications).
- *Usability* diagram, new actor references and new intentional element references are shown in the *New Object* view.
- *Cost* diagram is displayed in the *Deleted* view. DOORS user should delete manually the outgoing link before the object can be deleted. References in this diagram are deleted automatically.

Actors

Description of the changes:

- Add actor Web Developers
- Change Payment Gateway name and description
- Delete Bank Actor

Results in DOORS:

- *Web Developers* actor is displayed in *New Object View.*

- *Bank* actor is deleted (objects with incoming links are deleted automatically).
- Suspect incoming link to *Payment Gateway*.

Intentional Elements

Description of the changes:

- Add Service Usability softgoal
- Modify Need Products type (from goal to softgoal)
- Delete Cost of Products softgoal

Results in DOORS:

- *Service Usability* shows in *New Object View.*
- *Cost of Products* is deleted.
- Suspect incoming link for *Need Products*

GRL Strategies

Description of the changes:

- Modification of the attributes (intentional elements and actors)

Results in DOORS:

- Suspect incoming link to strategy: *Gateway to Customer with Encryption and Certificate*.

6.5 Chapter Summary

This chapter presented a Web credit card gateway case study. Using jUCMNav, we were able to model and analyse many aspects of this system's requirements.

In section 6.1, a URN model representing the high-level functional and non-functional requirements was developed. The model also includes four architectural alternatives. Then, in section 6.2, the model was refined using URN links. These links allowed discovering that the GRL view needed further decomposition, which was solved using a security of transactions catalogue. Section 6.3 focused on analyzing the model, using GRL strategies and evaluations for both intentional elements and actors. Using these analysis mechanisms, we found the best architectural solution for our Web credit

card gateway. Finally, in section 6.4, we linked the URN model to external requirements in DOORS, and tested the update mechanism by covering all types of updates (addition, modification, deletion) for GRL diagrams, actors, and intentional elements.

The next chapter is a discussion on our tool and approach to integrate goal and scenario modelling.

Chapter 7 Conclusions

This thesis presented several contributions that improve description and reasoning about functional and non-functional requirements. In the context of URN, we developed a usable and extensible tool that combines these two requirement types using goals and scenarios. This chapter contains a discussion on the goals and contributions of this thesis, as well as on the validation of the tool. Then, future work on jUCMNav and URN analysis is discussed.

7.1 Discussion

7.1.1 Goals and Contributions

As mentioned in section 3.1, the development of jUCMNav was focused on integrating goals and scenarios, an objective that was decomposed in four sub-goals (Figure 16 on page 34). In this section, we evaluate how our solutions satisfy the four sub-goals.

Common Metamodel

We developed two metamodels for URN: one to describe the abstract syntax of the notation and one to implement the tool. The latter metamodel was implemented on top of the UCM metamodel developed for jUCMNav 1.x.

The GRL metamodel has been developed based on the ITU-T draft standard [25]. However, few modifications to the draft standard, to support our interpretation of the notation, are implemented in the metamodel. For example, we determined that using all the link types supported by the notation would be difficult for new users of the notation. Thus, as a trade-off between usability and compliance to the draft standard, we preferred usability. We reduced the set of implemented link types to have something similar to other goal-oriented notations, such as the NFR framework. In addition, the constraints on dependencies were simplified and they became two-element relationships. Even if our implementation is not fully compliant with the ITU-T draft standard, we support the same

modelling concepts. For example, in our implementation, there is no mean-end links, but this association type is supported using OR-decomposition.

Implementing a more complete version of GRL in the metamodel and in our tool would be an easy task. During the development of jUCMNav, the metamodel has been modified several times, and the impact of modifications to the metamodel on the code was minimal.

Heymans *et al*. [21] also described a GRL metamodel that they developed to apply template-based analysis on the notation. Their implementation is inline with the standard. However, they did not have to deal with tool-support concerns and support for the complete URN notation in a pre-existing tool.

Integrated Tool Support

Our integrated tool support goal is itself decomposed in four sub-goals: editing goal and scenarios models, graphical completeness, usability, and reusable models. jUCMNav is an integrated environment used to develop GRL and UCM models. The editing of the models is realized using the same tools for each sub-notation. In addition, the tool's Outline, Properties and Elements views allow managing all the URN elements similarly.

Graphical completeness is also satisfied. In our tool, all elements in both GRL and UCM are represented graphically. In addition, we improved the representation of the GRL decomposition to support a view easier to understand, using a standard AND/OR graph format.

As an Eclipse plug-in, jUCMNav follows the user interface conventions of the platform. In addition, the multiple views of URN models available in the tool should be easy to use for anyone familiar with Eclipse. Some features, such as the drag and drop palette and outline, have a positive influence on the general usability of the tool. Finally, features such as the auto-layout and link routing help modellers develop URN diagrams that are simple to read.

Finally, GRL catalogues allow supporting reusable models, which is particularly useful for high-level goal decompositions and contributions, such as the security and security of transactions catalogues presented in this thesis. The catalogue files, described in XML, are also reusable in other tools.

Compared with other tools, we are considering that jUCMNav fully satisfies most of the URN-NFR goals we identified (Table 13). Multiple rounds of commitment is not considered fully satisfied because jUCMNav does not include any mechanism to create multiple versions of URN models, although some support is provided by the Eclipse platform itself. Usability of some aspects of the tool (e.g., label visibility and positioning, and diagram export) as well as modularity could still be improved.

URN-NFR Requirements	OME/ OpenOME	GRTool	TAOM4E	San-DriLa	jUCMNav
Expressing tentative, ill-defined and ambiguous requirements	++	--	++	++	++
Clarifying, exploring, and satisficing goals and requirements	++	+	++	++	++
Expressing and evaluating measurable goals and NFRs	+	++	--	--	++
Argumentation	+	--	+	--	++
Linking high-level business goals to systems requirements	-	--	-	--	++
Multiple stakeholders, conflict resolution and negotiation support	+	--	+	+	++
General and stakeholder's requirements prioritisation	--	+	+	--	++
Requirements creep, churn, and other evolutionary forces	++	++	--	--	++
Integrated treatment of functional and non-functional requirements	+	+	+	+	++
Multiple rounds of commitment	-	--	-	--	+
Life-cycle support	-	-	-	--	++
Traceability	--	--	--	--	++
Ease of use and precision	-	-	+	+	+
Modularity	--	--	--	--	+
Reusable Requirements	--	--	--	--	++

Table 13 jUCMNav versus Others Goals-Oriented Tools

Goal and Scenario Analysis

In this thesis, we presented multiple analysis methods now implemented in jUCMNav. The new analysis approaches include the qualitative evaluation algorithm for intentional

elements, actor evaluation labels, GRL strategies, URN links, and the impact of the GRL strategies on UCM models using URN links. These features exploit the full capabilities of integrated URN models. As shown in Chapter 6, they are useful at each step of the requirements engineering process, from requirements elicitation to requirements validation.

Links to External Requirements

Using the import/update process that was developed for UCM models as a basic framework, we implemented an approach that supports integrated URN models. This approach uses DOORS for integration with external requirements, hence supporting traceability, evolvability, and new types of completeness and consistency analyses. In the future, if needed, it would be possible to use a similar approach to link URN models to external requirements stored in other tools (other RMSs, Web servers, or Wikis).

7.1.2 Tool Validation

Validation of the jUCMNav tool was done at several levels:

- Each functionality of the GRL editor was implemented as an undoable command that contains preconditions and postconditions described with Java assertions. Any violation of these assertions generates a traceable error.
- A set of more than 100 automated (jUnit) test cases was integrated to the code. It is executed each time new code is committed to the repository (a SVN server) by CruiseControl scripts, and errors are reported automatically to the jUCMNav developers by e-mail. The tests especially target the editor commands. They currently all pass successfully but are kept as a regression test suite that can be extended to contain test cases for new functionalities.
- The DOORS export functionality has been tested using the case study in Chapter 6. GRL actors, intentional elements, and diagrams were successfully exported and also updated (after adding, modifying, and deleting actors, element, and diagrams in the model), hence providing a high coverage and confidence in this functionality.
- The tool and its features have been used by research groups from two universities (for theses and papers) and by 35 students from two sections of a requirements analysis course for an assignment and a course project (Fall 2006).

- The development of the tool has led to two publications at SAM 2006 [5][47].

7.2 Future Work

The integration of GRL and UCM in one tool opens the door to many new research possibilities. jUCMNav is currently being extended to support UCM scenarios, which will enable dynamic analysis of UCM models. These scenarios are defined in a user interface similar to the GRL strategies. Once implemented, it will become possible to add better analysis capabilities in jUCMNav by measuring the impact of strategic decisions on scenarios and architectural aspects of the model. For example, operational choices for goals, realized through tasks, have an influence on the system architecture. Using URN links, the UCM views could be modified depending on the operational choices defined in the GRL strategies. Such functionality would allow visualizing the impact of goals and non-functional choices through scenarios. For example, when intentional elements linked to components or responsibilities have denied evaluations (-100), it could be possible to hide them in the UCM model. Also, transformations from UCM scenarios could ignore those responsibilities and components.

In addition, support should be added for transformations from UCM scenarios to other artifacts. Then, it will be possible to enable transformations to MSCs, UML sequence diagrams, and test goals based on the two dynamic analysis mechanisms of URN (strategies and scenarios). This could complement suggested approaches like transformations from goal models to feature models [67].

It would also be simple to implement new evaluation algorithms for both intentional elements and actors, and use jUCMNav as a framework for their comparison. An interesting approach would be to develop a top-down evaluation algorithm for intentional elements. Such algorithm could be supported by defining which high-level intentional elements should be satisfied in priority. Then, the minimal evaluation values required for each of the lower-level intentional element would be calculated (if there is a solution). This algorithm could be inspired from the work on minimum-cost goal satisfiability described in [49].

For actor evaluation, an approach to improve the actor negotiation mechanism would be an algorithm that would maximize this evaluation. Using an approach similar to

the top-down algorithm just discussed for intentional elements, this new algorithm could use the intentional element references bound to actors as well as their priority and criticality to determine minimal values required by intentional elements.

To support model evolution in jUCMNav, an interesting feature to have would be a graphical comparison mechanism between two URN models. This would allow viewing graphically what was modified between two versions of a model (à la *diff*).

Future work also includes evolving GRL catalogues. Current catalogues are imported in URN models without keeping any references to the original catalogue. However, in the future, it would be interesting to build a repository of catalogues that could evolve over time. Catalogues would be imported dynamically in the model and could be synchronized with the repository. This feature would also require supporting parameterization of intentional elements to adapt catalogues to model contexts.

Additional development is required in the DXL library. A change report that is generated when linked requirements change is available only for UCM elements. This report should be extended to support integrated URN models.

Finally, further research is required on URN links. New features based on URN models could require new types of user-defined links, such as links from UCM to GRL. Such new links will require exploring better ways of representing and defining links in jUCMNav. An interesting tool feature would be to allow the definition of domain-specific *profiles* used to declare potential links of interest between UCM and GRL elements.

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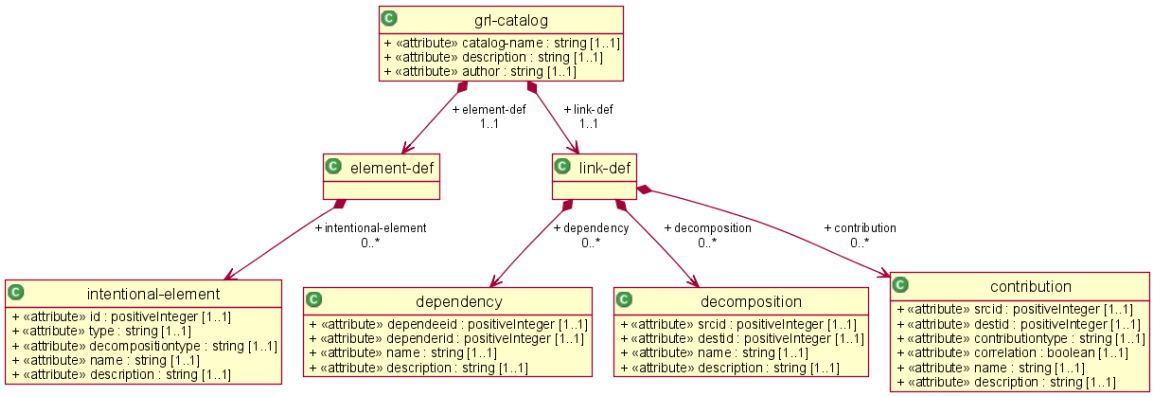
Appendix A: GRL Catalogue Schema

The XML schema for GRL catalogues is defined below, and a corresponding graphical overview (UML class diagram generated by the Hypermodel Eclipse plug-in) is also provided.

```
<?xml version="1.0" encoding="UTF-8"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
 <xs:element name="grl-catalog">
  <xs:complexType>
   <xs:sequence>
    <xs:element name="element-def">
     <xs:complexType>
        <xs:sequence>
         <!-- Intentional Elements List -->
         <xs:element maxOccurs="unbounded" minOccurs="0" name="intentional-element">
          <xs:complexType>
           <xs:attribute name="id" type="xs:positiveInteger" use="required"/>
           <xs:attribute name="type" type="xs:string" use="required"/>
           <xs:attribute name="decompositiontype" type="xs:string" use="required"/>
           <xs:attribute name="name" type="xs:string" use="required"/>
           <xs:attribute name="description" type="xs:string" use="required"/>
          </xs:complexType>
         </xs:element>
       <!-- End of Intentional Elements List -->
        </xs:sequence>
     </xs:complexType>
    </xs:element>
    <!-- Links definitions -->
    <xs:element name="link-def">
     <xs:complexType>
      <xs:sequence>
         <!-- Dependency -->
         <xs:element maxOccurs="unbounded" minOccurs="0" name="dependency">
          <xs:complexType>
           <xs:attribute name="dependeeid" type="xs:positiveInteger" use="required"/>
           <xs:attribute name="dependerid" type="xs:positiveInteger" use="required"/>
           <xs:attribute name="name" type="xs:string" use="required"/>
           <xs:attribute name="description" type="xs:string" use="required"/>
          </xs:complexType>
         </xs:element>
          <!-- Decomposition -->
          <xs:element maxOccurs="unbounded" minOccurs="0" name="decomposition">
           <xs:complexType>
           <xs:attribute name="srcid" type="xs:positiveInteger" use="required"/>
           <xs:attribute name="destid" type="xs:positiveInteger" use="required"/>
           <xs:attribute name="name" type="xs:string" use="required"/>
           <xs:attribute name="description" type="xs:string" use="required"/>
          </xs:complexType>
         </xs:element>
         <!--Contribution -->
         <xs:element maxOccurs="unbounded" minOccurs="0" name="contribution">
          <xs:complexType>
           <xs:attribute name="srcid" type="xs:positiveInteger" use="required"/>
           <xs:attribute name="destid" type="xs:positiveInteger" use="required"/>
           <xs:attribute name="contributiontype" type="xs:string" use="required"/>
           <xs:attribute name="correlation" type="xs:boolean" use="required"/>
```

```
          <xs:attribute name="name" type="xs:string" use="required"/>
          <xs:attribute name="description" type="xs:string" use="required"/>
         </xs:complexType>
        </xs:element>
       </xs:sequence>
     </xs:complexType>
    </xs:element>
    <!-- End of Links definitions -->
   </xs:sequence>
   <!-- GRL catalogue attributes -->
   <xs:attribute name="catalog-name" type="xs:string" use="required"/>
   <xs:attribute name="description" type="xs:string" use="required"/>
   <xs:attribute name="author" type="xs:string" use="required"/>
  </xs:complexType>
 </xs:element>
</xs:schema>
```

Graphical overview of the GRL catalogue schema:



Appendix B: Case Study Strategies

The following table represents the evaluation results for all the GRL strategies in the Web-application case study. It was generated using the jUCMNav CSV exporter.

Name	Description	Author	Shareholders (A)	Users (A)	Management (A)	Security	Security of Terminal	Security of Host	Encryption	Access Authorization	Identification	Authentication	Cardkey	Password	Biometric	Minimum Cost	Performance	Return on investment	Easy to use	Utilization of system by users	Training
Password_ Training_ Encrypt	Password strategy with training and encryption	Jean-François Roy	0	5	0	86*	90*	50*	100	100*	0*	100*	-100	100	-100	0*	-25*	0*	10*	78*	100
Password _noTraining_ Encrypt	Password strategy with no training and encryption	Jean-François Roy	0	5	0	86*	90*	50*	100	100*	0*	100*	-100	100	-100	0*	-25*	0*	10*	78*	100
Cardkey_ Training_ Encrypt	Cardkey strategy with training and encryption	Jean-François Roy	19	5	-62	86*	90*	50*	100	100*	0*	100*	100	-100	-100	-50*	-25*	13*	10*	78*	100
Cardkey_ Training_ NoEncrypt	Cardkey strategy with training and no encryption	Jean-François Roy	19	0	-62	38*	50*	0*	-100	100*	0*	100*	100	-100	-100	-50*	0*	13*	0*	50*	100
Cardkey_ noTraining_ noEncrypt	Cardkey strategy with no training and no encryption	Jean-François Roy	28	0	-31	38*	50*	0*	-100	100*	0*	100*	100	-100	-100	-25*	0*	19*	0*	0*	-100
Biometric_ Training_ Encrypt	Biometric strategy with training and encryption	Jean-François Roy	10	5	-93	86*	90*	50*	100	100*	0*	100*	-100	-100	100	-75*	-25*	7*	10*	78*	100
Biometric_ Training_ noEncrypt	Biometric strategy with training and no encryption	Jean-François Roy	19	0	-62	38*	50*	0*	-100	100*	0*	100*	-100	-100	100	-50*	0*	13*	0*	0*	-100
Biometric_ noTraining_ Encrypt	Biometric strategy with no training and encryption	Jean-François Roy	19	5	-62	86*	90*	50*	100	100*	0*	100*	-100	-100	100	-50*	-25*	13*	10*	28*	-100
Biometric_ noTraining_ noEncrypt	Biometric strategy with no training and no encryption	Jean-François Roy	19	0	-62	38*	50*	0*	-100	100*	0*	100*	-100	-100	100	-50*	0*	13*	0*	0*	-100
Cardkey_ noTraining_ Encrypt	Cardkey strategy with no training and encryption	Jean-François Roy	28	5	-31	86*	90*	50*	100	100*	0*	100*	100	-100	-100	-25*	-25*	19*	10*	28*	-100
Password_ Training_ noEncrypt	Password strategy with training and no encryption	Jean-François Roy	0	0	0	38*	50*	0*	-100	100*	0*	100*	-100	100	-100	0*	0*	0*	0*	50*	100
Password_ noTraining_ noEncrypt	Password strategy with no training and no encryption	Jean-François Roy	46	0	31	38*	50*	0*	-100	100*	0*	100*	-100	100	-100	25*	0*	31*	0*	0*	-100