Electronic Notes in Theoretical Computer Science 44 No. 4 (2001)

URL: <http://www.elsevier.nl/locate/entcs/volume44.html> 15 pages

Visual Design of Software Architecture and Evolution based on Graph Transformation

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Abstract

The paper suggests a two-level approach to describe visually software architectures and their evolution. One visual modeling formalism is used to describe the ar- chitecture level while another is used to model the behavior of each component (component specification level). Graph transformation is applied for both levels to describe the modeling formalisms and the model evolution in a formal way. The graph transformation based visual modeling approach GenGEd allows the designer to define the concrete and abstract syntax of each formalism. Thus, the choice of the visual formalisms is not restricted to existing ADLs or modeling languages but new visual languages can be defined by the user according to the problem domain. The architecture and component specifications are related over their abstract syn- tax. Here, it is possible to enforce coherence between the two levels while the user is changing the model in the editor generated by the GenGEd tool. The ideas are illustrated by a small example using UML-like class diagrams for the architecture and Petri net like networks for the component behavior.

# Introduction

The increasing complexity of software systems calls for methods and tools for easing their development. In component-based software engineering, problems like component interaction/migration and the overall design (architecture) of the system must be dealt with.

The software architecture research field is quite new (since the early 90ies) and there still does not exist a consensus on what should be the abstract de- scription of a software architecture. However, guidelines have been already provided. In particular, it is accepted that an architecture definition decom- poses into the types of elements *component* (computation unit or data store),

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*connector* (interaction unit) and *configuration* (architecture) [14]. As the no- tion of a component varies in literature, we here give the (implementation oriented) definition of Szyperski [19] which covers the most important aspects for the development of complex systems:

*“A software component is a unit of computation with contractually specified interfaces and explicit context dependencies only. A software component can be developed independently and is subject to composition by third parties.”*

An appropriate architecture representation has to follow this decomposi- tion paradigm and to support component interactions using an appropriate visualization. A visual tool environment for the visual description of an ar- chitecture should be available. Moreover, the tool environment should allow the user to perform syntactical checks on his model concerning e.g. the im- port/export relations between the component interfaces.

Architecture Description Languages (ADLs) [2] offer a well-defined set of notations for the description of an application architecture. Basically, an ADL allows the developer to describe the abstract organization of his system in terms of coarse-grained architectural elements, independent of the element’s implementation details.

Apart from the static architecture description, a major challenge in devel- oping and maintaining distributed software is *Evolutionary Change*, namely the problem how to handle changes in an existing system’s structure (software evolution). Often, it is desirable to extend existing software in an unforeseen way, e.g. the addition, removal or change of components or entire subsys- tems should be possible without having to plan for this design step before the system is started.

In [15], Kramer and Magee state that the key feature of change manage- ment is a clean separation of functional concerns of individual application processing components on the one hand and architectural coordination of components on the other hand. Additionally, we expect that a method for change management should have a formal background to allow mathematical reasoning and serve as a basis for tool support. The system architecture and the internal behavior of components should be specified by appropriate visual modeling languages. The method should relate changes on the architectural description level to the underlying component specifications and vice versa to allow syntactical checks of change properties.

Hence, we suggest an approach of employing visual modeling techniques on two levels, the architecture and the component specification. Evolution steps are specified as rule-based modifications on both levels. The focus of our concept is the independence from a specific visual modeling technique, taking into account the large variety of common architecture description languages and visual specification techniques. The user therefore may define a subset of an existing ADL or own visual modeling languages adapted to his purpose. Thus, we aim at a generic visual modeling approach for model evolution at the design level.

Our approach is based on GenGEd [1], a visual modeling approach sup- porting the syntax specification of arbitrary visual modeling languages. Gen- GEd is based on the formal specification technique *Algebraic Graph Transfor- mation* [3], thus allowing rule-based modifications of the system behavior as well as the architecture. The formal basis also gives rise to analyzing properties of components and their connections (see e.g. [21] for a first discussion). Gen- GEd admits the visual specification of a visual language and (up to now) au- tomated editor generation for diagrams of this language. Graphical constraint solving techniques are used to compute the layout of diagrams. GenGEd has been successfully applied to a variety of visual modeling techniques, including simplified versions of UML class diagrams, statecharts, Nassi-Shneiderman diagrams and Petri nets.

Figure 1 illustrates our two-level concept. For the architecture level we use simple graphs. The component specification level allows arbitrary visual models and their relations. These visual models may be given in terms of graphs (then we have distributed graphs in the sense of [20]), Petri nets, algebraic specifications etc. In order to tackle the problem of changing large and complex systems we identify two different kinds of change. Changing the architecture implies changes on the specification level as well. Changes of the models at the specification level may but need not induce changes of the architecture. Figure 1 shows a graph transformation rule specifying a global change step. The left-hand side of a rule (*L*) specifies the parts of a graph the rule can be applied to. If the right-hand side (*R*) does not contain some of these parts, they are deleted by the rule. If *R* contains new parts, these are added. Parts common to both sides are preserved by the rule.

# L



2

3

1

4

5

*S2 S3*

*S1a*

*S4*

*S5*

R

architecture level



2

1

6

3

5

*S2 S3*

*S6 S1b*

*S5*



component specification level

Fig. 1. Two-level approach to model evolution

The rule in Figure 1 describes changes on both levels. At the architectural level, node 4 is deleted and node 6 is added. Correspondingly, the specifica- tions of their subsystems are deleted (*S4*) and added (*S6*) at the specification level. The specification *S1a* in *L* is changed to the specification *S1b* in *R*.

The paper is organized as follows: In Section 2, we illustrate our ideas of rule-based model evolution using the specification of a simplified UNIX print server as example. We use a language similar to UML class diagrams as architecture design language and Petri nets to specify the component behavior.

Section 3 presents the use of GenGEd for our approach and discusses the

formal backgrounds of our concepts.

*Acknowledgements*

This work is supported by the German Research Council (DFG) as part of the work of the Forschergruppe Petri Net Technology, by the German-Brazilian Cooperation for Graphical Support of Formal and Semi-Formal Methods for Software Specification and Development (GRAPHIT), and by the German Federal Ministry of Education and Research (BMBF) as part of the research project Continuous Engineering for Evolutionary I&C Infrastructures. We also would like to thank our anonymous referees for their most valuable hints.

# Example: A Print Server

A component called printServer is part of a (distributed) operating system and offers services to print documents. To realize these services, the com- ponent relies on other components’ services. A system user calls a service directly by a system command or indirectly via an application. A print job is queued in a printer queue (invisible for the user) and is processed later. The user may call for a list of his currently running print jobs (service lpq), add documents to the printer queue (service lpr) or remove a single job from the list of his print jobs (service lprm). The class printServer offers (exports) these services. For their realization, a printServer component needs the user administration service checkAccess from the SystemAdmin component to check whether a user is authorized to print or not. If not, an error message is sent to the user by email using the mail service offered by the MailSystem component. The components printer and priorityQueue offer services for printing and for adding/removing print jobs to/from the priority queue.

From this scenario, we derive the classes for components of our system yielding the architecture level illustrated in Figure 2.

A graphical notation similar to UML class diagrams is employed. Com- ponents offer services via export interfaces which are based on a contract principle: an ADT-like signature [4] specifies in the traditional way the names and required service calls. Services needed from other components are listed in a component’s import interface. Here, only method names are given, not their complete signature. Hence, a component is divided into the three blocks *export interface* (upper block), *component name* (middle) and *import inter- face* (lower block). Association arrows represent import/export relations on component services. We do not consider inheritance relations here in order to keep our example simple.

For the specification of the component behavior, we use Open Algebraic High-Level Nets [17]. Each of the printServer component’s offered services (an operation in a class signature in the architectural level) as well as inter-

|  |
| --- |
| print: Doc -> () | ErrMsg |
| **Printer** |
| mail, getFirst, remElem |

|  |  |
| --- | --- |
| lpr: Doc, UId -> JobId lpq: UId -> List[JobInfo] lprm: JobId, UId -> () | |
| **PrintServer** | |
| print, mail, addElem, getFirst, elements, remElem, checkAccess | |
|  |  |

|  |
| --- |
| checkAccess: UId -> Priority | ErrMsg |
| **SysAdmin** |
|  |

|  |
| --- |
| mail: UId, Msg -> () |
| **MailSystem** |
|  |

|  |
| --- |
| addElem: JobInfo, PrioQueue -> PrioQueue remElem: JobInfo, PrioQueue -> PrioQueue getFirst: PrioQueue -> JobInfo  elements: PrioQueue -> List[JobInfo] |
| **PriorityQueue** |
|  |

Fig. 2. Architecture level of the print server example

nal services are represented as so-called service nets at the specification level. Hence, a component class corresponds to a number of service nets. Input and output parameters of a service call are made explicit in the corresponding service nets by special input and output places. The service nets show con- currency and synchronization of methods as well as the exclusive or shared use of resources. There may be a hierarchy of service nets starting by the interface services on top which rely on internal services again represented as service nets. In our example, the component printServer is specified by four service nets, three for the exported services lpr, lprm and lpq and one for the internal service printFirst realizing the printing of the first job in the prior- ity queue. The use of services from other components is depicted as gray transitions with the same name as the corresponding service of the export- ing component. Analogously, shared resources (e.g. the priority queue) are represented by equally named gray places in different nets. Operations repre- sented as arc inscriptions in algebraic high-level nets are formally defined in corresponding algebraic data type specifications (see e.g. [16]). As we chose self-explaining operation names (or variables) we here omit the formal data type specifications for our nets.

The service net for lpr (Fig. 3) shows how the user access to a printer is checked by the SystemAdmin method checkAccess at first. If the user is allowed to print, checkAccess computes a priority, and an object of type JobInfo is generated containing the user id, the document and a new job id. This JobInfo object is added to the priority queue (a shared place which is also used in all other printServer service nets). The method returns the job id or, if the user is not allowed to print, an error message is sent to him by email.

In the net for lpq (Fig. 4) a list of current job infos in the priority queue is read by the method elements from the component priorityQueue. The user

lpr



Doc

newJobInfo

JobInfo

doc newjinf(uid,prio,doc,newjid) Priority

checkAccess

prio(uid)

jinf

PrioQueue

qu

getJid(jinf)

uid

prio

Acc(UId)=true

+qu(qu,jinf) addElem

UId

checkAccess

uid

Acc(UId)=false

AccessError

uid

uid,

"No Access to Printer"

mail

JobId

Fig. 3. Service net for the method lpr



qu

lJId

lJId

uid

uidlist(uid,lJid)

List[Jobinfo]

UId

lpq

PrioQueue

elements

List[JobInfo]

filter

Fig. 4. Service net for the method lpq

ids of the entries in this list are compared to the current user id on the input place and a new list containing only those entries with the same user id is computed and returned by the method.

UId



uid

lpq

jlist

List[JobInfo]

PrioQueue

lprm

jid

jlist

job(jid,jlist)

qu

jinf

-qu(qu,jinf)

JobId

getRmJob

JobInfo

remElem

Fig. 5. Service net for the method lprm

The net for lprm (Fig. 5) uses the method lpq to compute a list of the user’s print jobs in the priority queue. From this list, the entry with the corresponding job id is filtered and removed from the queue.

The internal service net for printFirst (not depicted here) realizes the print- ing and removing of the first job of the priority queue. This service is inde- pendent of system user calls and is running continuously – in parallel to the other services – as long as there are jobs in the queue.

Evolution steps are modeled by changes within a service net (local changes) that do not alter the input and output parameters, or by changes of the archi- tecture (global changes), e.g. by removing/adding components or by changing a method signature. Global changes at the architecture level influence the component specification level. Whenever components are added or removed, method nets have to be added or removed, too. When a method signature is changed, the service has to be adapted accordingly. Examples for global changes are e.g. the addition of a Scanner component class (plus the needed

service nets), or the removal of the

MailSystem

component. Here, all mail

service transitions also have to be removed out of service nets. A local change

would be to alter the behavior of the lpq method to return the complete job list of the priority queue and not only a single user’s jobs. Here, only the internal net is changed whereas the method’s signature remains unchanged.

As we use class diagrams at the architectural level we realize an abstract and open design: The addition of a new printer to our system would not change the model because a printer is an instance (object) of the printer component class.

Obviously, a combination of both levels is necessary to decide whether a change has global effects or not and to perform consistency checks. For ex- ample, it should be possible to ensure that the methods in export interfaces at the architecture level are consistently refined to service nets at the com- ponent specification level and that a method’s signature corresponds to its input/output places in the corresponding service net. Hence, in the next sec- tion we introduce the GenGEd approach to formally specify model evolution and show how the combination of both levels is realized and forms the basis for checking dependencies in model evolution steps.

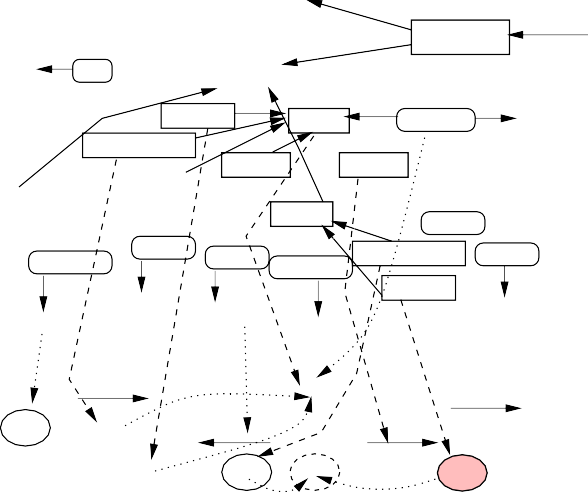
# The Visual Environment GenGEd

GenGEd is a visual environment supporting the visual specification of visual languages [1]. The visual specification is used to generate a graphic editor for the manipulation of visual sentences over the specified language. Visual sentences are diagrams (or instances) of a visual language. The specification of visual languages is given by a visual alphabet and a visual grammar. We distinguish the abstract syntax and the concrete syntax of a visual language. The abstract syntax offers the basic relation into the application domain. Here, it is possible to define semantic dependencies of language elements. The concrete syntax describes the layout of symbols and their links. For the transformation of instances (diagram manipulation) we use the Single Pushout approach to algebraic graph transformation [3]. This approach is implemented by the Agg system [5]. The vertices’ graphical attributes are calculated by constraint solving mechanisms using the ParCon constraint solver [9]. Both Agg and ParCon are integrated in the GenGEd environment [1].

Our approach integrates two visual modeling languages using GenGEd. The integration is realized by the abstract syntax. Here, in addition to the language’s elements, items are specified used for the combination of both lan- guages. In our print server example from Section 2, these are the language of class diagrams for the architectural level and the Petri net language for the specification of component behavior. Thus, it is possible to relate items of the architecture level to items of the component specification level. For example, an exported method at the architectural level is always related to a service net at the specification level.

*Defining Language Elements: The Visual Alphabet*

Fig. 6 illustrates the visual alphabet of the two-level language. In the mid-



String CN

ADL-Class

String IN

String EN

ImpMethod

ExpMethod

beg

end

from

to

Combine

completeView

String SN

Bool

shared

not\_shared

Trans

TrName

ArcTP

ArcOTP

InsTP

String

ArcPT

InPlace

ArcIPT

Place

PlName

InsPT

InsPT PlName not\_shared

OutPlace

InsTP PlName

String

shared

String

String

String

String

String

String

**Concrete Syntax**

**(Service Net)**

OutInterf

ADL-Assoc

**Abstract Syntax**

**Concrete Syntax**

**(Class Diagram)**

Service Net

InInterf

Fig. 6. Visual alphabet of the two-level language combining Class Diagrams and Petri Nets.

dle of Fig. 6, the abstract syntax of all language elements is illustrated. All lexical symbols comprising the abstract syntax are visualized by rectangles and all data attribute symbols by rounded rectangles. The upper part of the abstract syntax area contains the elements of the class diagram language and the lower part elements of the Petri net language. Both are connected along the element Combine that relates each exported method (element ExpMethod) to a service net (element ServiceNet). We have equipped the item Combine with an attribute symbol containing a boolean value completeView. This value is controlled by user interaction in the intended graphical editor for our com- bined language. The user interaction should be realized in the graphical user interface by a button the user can press if he wants to see the Petri nets for the methods (completeView = true) or to hide it and only see the architectural level (completeView = false). Thus, a simple view concept controlled by the abstract syntax can be realized as well.

The graphical layout of the abstract elements is shown in the top and the bottom of Fig. 6. In the GenGEd approach, the relation between abstract and concrete syntax is modeled by graphical attributes for each symbol and link in the abstract syntax. The graphic attribution is visualized by dashed arrows in Fig. 6. Graphical constraints between symbol graphics are visualized by dotted

arrows. For example, we require that an arrow between two components (the layout of ADL-Assoc) always begins (respectively ends) at the corresponding rectangles (the layout of ADL-Class). A shared place or transition is visualized as gray coloring of the corresponding item. This is modeled by two possible language items shared and not shared connected to the place and transition symbols. The item shared is depicted as gray object, the item not shared as white one, with the same position as the underlying ellipse (place) or rectangle (transition). The visual rules ensure that exactly one instance of shared or not shared is connected to one place or transition instance.

Formally, instances over a visual alphabet are graphs over the alphabet type graph satisfying the constraint satisfaction problem (Csp) which is de- rived from the alphabet. The computed solution of the Csp affects the sizes and the positions of the graphics. Fig. 7 illustrates one instance. We omit the inscriptions in the Petri net for better readability. This instance has one component named C at the architecture level containing one service method (test). The service net for this method consists of one input and one output place and a shared transition in between. Both levels are visible (completeView

= true).



test

SN

**Abstract Syntax**

CompleteView

EN

ExpMethod

CN

true

ArcIPT ArcOTP

InPlace Trans OutPlace

test

ADL-Class

shared

C

**Concrete Syntax**

test

C

test

Service Net

InpInterf

OutInterf

Combine

Fig. 7. One instance of the two-level language.

*Ensuring Consistency: The Visual Grammar*

Instances also occur in visual grammars that allow for syntax-directed editing in an intended graphical editor. The grammar rules ensure that only syntacti- cally correct visual instances can be maintained in the editor and that certain consistency conditions are satisfied by the visual sentences (diagrams) drawn in the editor. The left and right-hand sides L and R of a rule may contain variables that are mapped to concrete values when the rule is applied to a vi- sual sentence. Moreover, a rule may contain a negative application condition (NAC) specifying a situation that must not occur if the rule is to be applied. Fig. 8 illustrates a rule which supports the insertion of a class symbol together with a class name. The NAC ensures that there is not yet a class

with the same name.

**NAC**

CN

ADL-Class

**L**

**R**

CN

ADL-Class

insClass(cn)

cn

cn

cn

cn

Fig. 8. Rule for inserting a class symbol

The rules that realize the combination of both levels and ensure consis- tency, are the rules insExpMeth and insImpMeth allowing to add an export or an import method to a class. The rule insExpMeth is coupled to the generation of a service net (see Fig. 9). We use the shorthand em for export method in Fig. 9 for the concatenation of the strings en (export method name) + s1,s2,..., sn (parameter sorts of the method) + s (target sort). Rule insImpMeth is com-

**R** ADL-Class



Combine

Service SN Net

ExpMethod completeView

InInterf

true

en

OutInterf

EN InPlace



ExpMethod EN

em

em

ADL-Class

...

**NAC**

ADL-Class

**L**

em InPlace

OutPlace

insExpMeth

PlName

InPlace

PlName

(en,s1,s2,..,sn,s)

s1 PlName s

s2 PlName

sn

em

en ...

Fig. 9. Rule for inserting an export method

bined to the insertion of an association between two class symbols. Here, two cases are distinguished. The first rule is applied if there exists already an association: the import method name is added to the import section of of the class. The second rule is applied if no association arc exists to the class ex- porting the method: here, the association is inserted and the method is added to the import section.

At the Petri net level specifying a service net requires rules to insert places, transitions and arcs labeled by names and arc inscriptions. Fig. 11 shows the rules for inserting a place. Here, it is important to keep the color of shared

/ not shared objects consistent. We need three rules for different situations: Rule insNewPlace(sn,pln) inserts a place pln in net sn. The place named pln did not exist in any service net before; hence it is marked as not shared. Rule insShareFirstTime(sn,pln) inserts a place that is shared with a place of the same name of another service net. Up to now this place has been not shared. The rule therefore marks both places as shared after the insertion. Rule insSharedPlace(sn,pln) inserts a place that is shared with more than one other places (already marked as shared). This new place also is marked as



**L**

**R** x:ADL-Class

y:ADL-Class

ExpMethod

insImpMeth(en)

ExpMethod

em

EN

ADL-Assoc ImpMethod

en IN

em

EN

ADL-Assoc

y:ADL-Class

x:ADL-Class



y:ADL-Class

ExpMethod

em

EN

**NAC**

**L**

y:ADL-Class

**R** x:ADL-Class

y:ADL-Class

x:ADL-Class

ExpMethod insImpMeth

(en)

em

ADL-Assoc ImpMethod

en IN

ExpMethod

em

EN

EN

ADL-Assoc

x:ADL-Class

Fig. 10. Rules for inserting an import method

shared by the rule.

We here do not depict all rules (e.g. we omit the insertion rules for tran- sitions and arcs), but their definition works analogously to the depicted rules. Additionally, rules deleting and changing elements in the editor have to be included in the grammar.

Summarizing, using the GenGEd approach, an evolution step is a graph transformation induced by the application of one or more rules to a graph (a sentence of our visual language) that models a system on the two levels architecture and component specification. The rules ensure that the evolution steps are consistent (e.g. no method is added in the architectural level without a corresponding service net being generated). Additional checks may be added by enhancing the abstract alphabet and the grammar rules.

# Related Work

Several different research areas overlap with our work including architecture design techniques, architecture transformation, distributed systems engineer- ing and evolutionary system development. As the main focus of our work lies in the evolution of visual models, the areas of software visualization and visual languages also relate to our approach.

An overview over architecture description languages (ADLs) based on com- ponents and connectors can be found in [14]. In our example we use architec- ture design diagrams related to UML class diagrams. Work on architecture descriptions based on (extended) UML diagrams is done in [13] and [18] where the aim is to validate architectural properties by formal means.

In Object Coordination Nets (OCoNs) [7] a UML architecture description is combined with Petri nets specifying the component behavior. This idea



**R** sn SN

**L**

**NAC**

PlName

pln

insNewPlace (sn,pln)

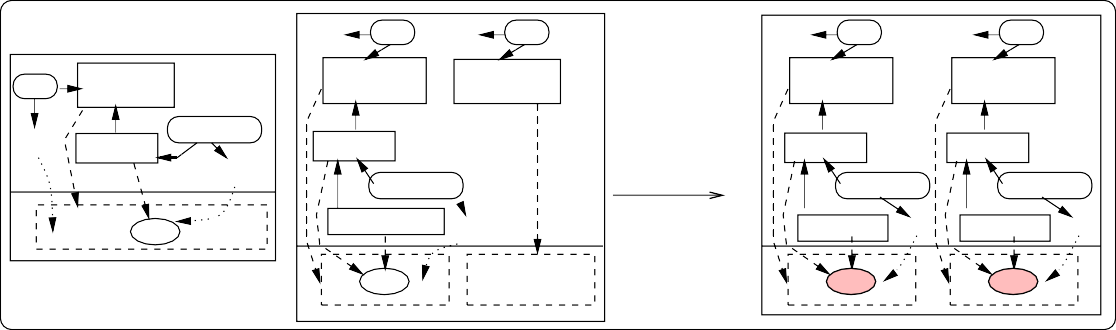
Service Net

pln PlName

Place

sn SN Service

Net



**NAC**

SN

**L** sn1 SN sn SN

**R** sn1 SN

sn1 SN

2:Service Net

1:Service Net

2:Service Net

1:Service Net

2:Service Net

sn

Place

PlName

pln

Place

PlName not\_shared

insPlace-

SharedFirstTime (sn,pln)

Place

PlName

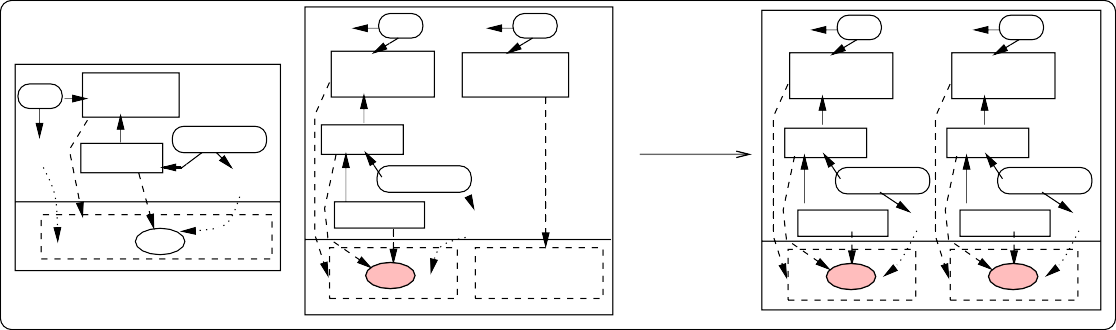
Place

PlName

pln shared pln shared pln

|  |  |  |
| --- | --- | --- |
| Place |  | not\_shared |
|  |

Fig. 11. Rules for inserting a place



**NAC**

**L** sn1 SN sn SN

**R** sn1 SN

sn1 SN

SN

2:Service Net

1:Service 2:Service

Net Net

1:Service Net

2:Service Net

sn

Place

PlName

pln

Place

insSharedPlace (sn,pln)

PlName

shared

Place Place

PlName PlName

pln

shared

pln

shared

pln

serves as example for our two-level approach presented in this paper. The OCoN tool environment supports the visual development of OCoNs but not their relation to the architectural level. Other examples for visualizing archi- tecture and (restricted forms of) their evolution can be found in ADL tool environments [2]. None of these tools allow a generic description of the visual model as we suggest in our approach using GenGEd.

We model evolution steps by graph transformation which is also subject to considerable research. Software architecture reconfiguration based on graph transformation is presented by Wermelinger and Fiadeiro in [22]. They in- troduce a uniform algebraic framework based on category theory where an architecture is given as a graph whose nodes are refined to programs. Re- configuration steps are modeled by conditional graph rewriting rules. In [20], Taentzer introduces Distributed Graph Transformation. In this formal spec- ification technique an architecture level (network graph) and a component level (local graphs) are distinguished. This work is extended in [8] integrating distributed graph grammars and consistency checking rules. Our two-level ap-

proach is based on this work but allows more flexible visualization techniques than graphs for both levels.

Related approaches are given in [6,11,12] where software architecture graphs are transformed to adapt them to new requirements or to reduce the compo- nent interrelations. In our paper, we restricted to ”editor evolution”, i.e. changes are performed in the model editor, but our editing rules incorporate the checking of consistency conditions. Another formal approach to software system evolution is given in [10]. Here, properties of component interrelations (i.e. invariants and dependencies) are formalized by a modal logic to enable consistent modifications in evolution steps. These invariants also might be expressed within graph rules for visual modeling.

# Conclusion

We introduced our concept of visual model evolution and illustrated the basic notions using a small print server example. The main ideas are on the one hand a concept of visually representing a system on two levels and on the other hand a rule-based approach for the description of consistent system evolution. We then have reasoned about the benefits of a visual environment for the em- ployment of visual modeling techniques at two levels of abstraction discussing the GenGEd approach and its advantages in this context. In general, exist- ing tools supporting visual modeling are restricted to a fixed visual modeling language. Moreover, they are often complex and not easy to use because they are intended to cover as many software engineering steps as possible. The advantage of the GenGEd approach is to support the generation of a small application specific visual modeling environment.

Some future work is needed to use the formal basis of our approach to formalize and check e.g. invariants of component behavior and interrelations in an appropriate way. Accordingly, we will enhance the GenGEd tool en- vironment in order to model and check system behavior. More examples and larger case studies using different visual modeling techniques will be investi- gated to validate the usefulness of our approach towards a rapid prototyping environment for visual model evolution.

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