SEMI-AUTOMATED LINKING OF
USER INTERFACE DESIGN ARTIFACTS

by

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ABSTRACT

User centered design involves the creation of design artifacts such as task and architecture models. It is increasingly accepted that such artifacts cannot effectively be created separately, but instead coevolve incrementally, so that information obtained from the development of one artifact contributes to the development of the others. In user interface development, different people with different backgrounds typically participate in the development of these artifacts. Consequently, communication is important for coevolution. This research demonstrates how different design artifacts can be linked semi-automatically. We illustrate this technique using *Adligo*, a computer-based tool for generating links between the User Action Notation (UAN) task model and the Clock architectural model. Our results show that in two case studies, we were able to generate 90% of possible links with error rate of 0% to 12% with limited human assistance.

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Chapter 1

INTRODUCTION

Designing an interactive system consists of a set of processes such as task modeling, user interface design, task-oriented specification, and implementation. Each process results in an artifact that expresses information contributing to the usability of the developed system. Developers increasingly accept that such artifacts cannot be effectively created separately, but instead coevolve incrementally, so that information obtained from the development of one artifact contributes to the development of the other [BROWN et al., 1998]. The need for a concurrent development is more apparent in designing user interfaces which demands iterative refinement.

Figure 1.1 shows some of the design artifacts produced in the process of developing an interactive system. In this process, software engineers and Human Computer Interaction (HCI) designers concurrently produce a set of design artifacts such as task hierarchy (or model), user interface design (e.g., screens, mockups, and scenarios), task-oriented specification (in the User Action Notation [HARTSON et al. 1990]), software architecture (e.g., the Clock architecture style) and code (e.g., the Java language).

Figure 1.1. *Coevolutionary design of interactive systems. The design process leads to a set of artifacts, which are developed iteratively and incrementally. Improvements in one artifact contribute to improvement in the others. Different artifacts represent the point of view of different participants in the design process [BROWN et al., 1998].*

Failing to relate the design artifacts causes lack of communication between their developers. Correlating information provided in the design artifacts allows the designers to see how knowledge from one design artifact can be applied to another. It is difficult to correlate design artifacts because they express information from different point of view (e.g., the users' view vs. the implementer's view) and at different levels of abstraction (e.g., code is much more detailed than architecture) [GRAHAM et al., 1996b].

To facilitate the communication between designers, Brown et al. [BROWN et al., 1998] developed the *Lista* tool which visually showed different user interface design artifacts linked together (see figure 1.2).

Figure 1.2. Different views linked in Vista: (a) the task model; (b) the task-oriented specification in the UAN; (c) the Clock architecture of the application, and (d) the Clock code. The Vista display has been manually annotated to show some of the links between the design representations.

1.1 Problem and Motivation

Vista allows designers to simultaneously navigate a hyperlinked task hierarchy (model), task-oriented specification, software architecture, and code documents. However, Vista has one significant shortcoming. Links in Vista are hard-coded and specified by hand. In our experience, we may need to manually specify over 100 links for a medium size case study (see chapter 6: Experiments and Analysis). The problem gets more challenging if we wish to maintain these links and validate them as the design artifacts evolve. In this case, the link generation process is necessarily iterative in order to maintain the correlation between the design artifacts.

To solve these two problems, we have to think of a new approach that facilitates creating and maintaining the links in a more automatic manner than the manual approach adopted in Vista.

1.2 The Purpose of This Thesis

Figure 1.3 shows the types of links that can be browsed using Vista. The current Vista tool can automatically generate these links between the architecture model and the code (link 2), and between the task model and the task-oriented specification (link 4). Generating these links is possible because the architecture model is a high-level design artifact for the code, and both lie in the *constructional* domain. Similarly, the task model is a high-level design artifact of the task-oriented specification, and both lie in the *behavioral* domain.

Links 1, 3, 5, and 6 are challenging to generate because they map artifacts lying in different domains. If we generate one type of these links we will be capable of mapping any design

Figure 1.3. Types of links that correlate different user interface design artifacts. Generating links 2 and 4 is easy because they map artifacts lying in the same domain. Links 1, 3, 5 and 6 map behavioral design artifacts to constructional.

artifact to another through the other links. Accordingly, we chose to investigate how to generate the links between the architecture and task models.

We argue in this thesis that we can generate links between task and architecture models semi-automatically. We use the User Action Notation (UAN) [HARTSON et al. 1990] as a task model and Clock architecture [GRAHAM AND URNES, 1996] as an architectural model. We could use other models in our work since they have many common features, as shown in the literature review presented in chapter 2.

In fact, the UAN specifications are far from implementation because moving from the UAN to Clock architecture requires a change in point of view, from the behavioral view of the UAN to the architecture implementation. As such, the main issue of mapping one of these models to the other is the change in point of view, not the change in level of notation.

In addition, the Clock architecture (which is used by software engineers) can be easily processed by a computer-based tool due to its well defined formality [GRAHAM, 1995], while the UAN descriptions (used by HCI designers) contain prose [HARTSON et al. 1990] which is hard to process automatically.

1.3 Our Approach to Solving This Problem: *Adligo* Methodology

In this research, we demonstrate how different design artifacts can be linked semi-automatically by developing *Adligo*¹, a prototype tool for generating links between task and architecture models with human assistance. This assistance is represented by a newly introduced artifact called the *dictionary*, which translates the UAN names to the Clock architecture names. As opposed to the traditional linguistic dictionary, this dictionary contains mapping *rules*, which are written in a simple *pattern language* we have designed for this purpose (see chapter 4).

However, the solution for linking the UAN model to its corresponding Clock architecture is not a naive translation from one notation to another. Rather, it is a matter of transforming the behavioral view, represented by the UAN task model, to the constructional view represented

¹ *Adligo* is a Latin word, which means, "I connect".

by the Clock architecture model. Therefore, in addition to the dictionary, Adligo needs a few internal hardwired rules (see chapter 5) to be able to generate sufficiently correct links.

Through these rules, Adligo becomes semi-automatically able to derive links between the models. We used the *Usta* tool [BROWN et al., 1998] to graphically browse the generated links between the UAN notations and the Clock architecture (see chapter 3).

1.4 Results and Analysis

In order to get a sense of how well Adligo performs, we focused in our experiments on two case studies: the *CPM Planner* and the *Video Annotator* applications (see chapter 6). Our results show that in these two case studies, we were able to generate 90% of possible links with error rate of 0% to 12% with only 8 rules in the dictionary. However, we believe that further experiments are required to determine whether these results generalize to applications of Adligo.

1.5 Contributions

The contributions of our work are summarized in the following points:

1. We developed a method to semi-automatically derive links between task and architecture models. This method has been demonstrated by a computer-based tool called Adligo.

2. We developed a new computer-based tool (*Adligo*) for generating links between the UAN task model and the Clock architecture model. This tool is fully integrated with the *Vista* tool which visually exposes the hyperlinks generated by *Adligo*.

1.6 Road Map

Chapter 1: *Introduction* gives a research overview, problem statement and motivation, the provided solution (*Adligo*'s methodology), list of contributions, a summary of the results, and a road map for this thesis.

Chapter 2: *Related Work* provides a literature review. The chapter consists of three main parts. The first describes the task models and gives several examples for task modeling techniques. The second is concerned with describing architecture models commonly used in software engineering. This survey of models alerts us to their common characteristics. The third part reviews some efforts similar to our work.

Chapter 3: *Design Artifacts Browsed in Vista* explains the UAN notation, how it is used as a task model, and how it is employed to write task-oriented specifications. This chapter gives also a detailed description of the Clock architecture. Finally, it describes the *Vista* tool, which is the motivation of our work.

Chapter 4: *Semi-Automated Link Generation Process: The Adligo Tool* explains in detail the link generation process for *Adligo* users. It describes the general framework of the process and gives an introduction tutorial for generating the links by *Adligo*. This chapter discusses many

details related to new concepts presented in this research such as the *dictionary* and the *pattern language*.

Chapter 5: *Looking Under the Hood: The Implementation of Adligo* explains technical aspects related to Adligo's implementation. The discussion in this chapter is supported by formal specification for the functions used in Adligo's methodology.

Chapter 6: *Experiments and Analysis* provides an evaluation of the Adligo tool. It gives a description of the experiments we performed. In this chapter, we determine the measures by which we evaluate Adligo's performance. Also, we discuss our results and analyze them.

Chapter 7: *Conclusion* highlights the main ideas discussed in this thesis and gives directions for future research.

Chapter 2

RELATED WORK

In this thesis, we show that generating links semi-automatically between task and architecture models is possible. This chapter provides a literature review of some task and architecture models, and a review of similar efforts to link them together.

The chapter consists of three parts. The first describes four task models commonly used in designing user interfaces. The second part describes four architecture styles used in the software engineer community. The last part describes some efforts similar to our work.

The work in this thesis is based on the hierarchical form of task model. We survey this class of task model, but base our work on a single representative, the User Action Notation (UAN). Similarly, a wide range of architectural style for user interface development are based on layered variants of the model-view-controller style. We survey these architectural styles and choose the Clock architecture style as a representative on which to base our work. We believe that because these models (UAN and Clock) are representative of wider classes, the techniques presented in this thesis may have wide applicability.

TASK: Select a mode		
USER ACTIONS	INTERFACE FEEDBACK	INTERFACE STATE
~[mode] Mv	mode-! : mode!, $\forall$ mode'! : mode-!	selected = mode
M^		

Figure 2.1. UAN description for the task "select a mode". The table shows the interface feedback and its state as a response to the user actions.

2.1 Task Models

A task model records the tasks that potential end-users of the system may need to perform to do their jobs, independent of dealing with a particular computer system. The design of an interactive system is based on supporting these tasks. This section describes some task-modeling techniques. We conclude this part by a summary in which we report the common features among these models.

2.1.1 The User Action Notation (UAN)

The User Action Notation (UAN) [HARTSON et al. 1990] is a task-oriented notation that describes the behavior of the end-user and the interface as they perform a task together. The UAN was initially intended to be the communication means between interface designers and the implementers. We use the UAN to describe task models (see section 3.1) and task-oriented specification encoding how tasks are carried out with the user interface, from the point of view of the end-user. HCI designers use the UAN to encode their tasks in a tabular format (see figure 2.1).

UAN symbols are meaningful mnemonics and can be typed using a standard keyboard. The UAN notation supports temporal relations between tasks [HARTSON AND GRAY, 1990].

The UAN provides task coverage as it shows whether all the intended system tasks are supported in a reasonable and consistent way. The UAN explicitly shows which tasks are supported by the system and consequently helps in understanding how the system fits within the context of its use.

In comparison to specifications using scenarios, mockups or prose, the UAN provides higher precision and accuracy. This is especially true of specifications of the concurrent properties of user interfaces which are important to groupware applications.

UAN has, however, the following disadvantages [GRAHAM et al., 1996b]:

Cumbersome and Tedious: UAN specifications for complex systems can run over dozens of pages. This makes reading difficult and searching for subtasks a hard job.

Difficult to Maintain: Changes in a user interface design can require considerable change in its corresponding UAN specification. Provided that design is always evolving, the UAN is typically left behind as designers become unwilling to spend the time updating it.

These two points are addressed through a browser [Telford, 1996] which supports easy navigation of the UAN specifications. Such a browser may evolve to a complete editor.

Hard to Transform to Implementation Domain: The linkage between the UAN specifications and their implementation is not clear. Some studies have been done to bridge the gap between

task-oriented specification and implementation [GRAHAM et al., 1996b]. Our work in this thesis falls in this category as we try to link the UAN task model with the Clock architecture model.

2.1.2 ConcurTaskTrees

ConcurTaskTrees is a graphical notation for describing tasks with a wide range of temporal relationships. The task in this approach is described by the following attributes [PATERNO et al., 1997b]: Name, Type, Objects, First Action and Last Action. To construct the task specification, *objects* must be identified and *communication actions* must be defined. There are two types of objects:

Perceivable Objects: items which end-users can sense, such as menus, icons, windows, voice, sounds, and so on. They can belong to application or interaction tasks.

Internal Objects: entities which belong to the application, like the database.

Actions can be cognitive, logical, or physical. We can identify four types of tasks:

User tasks require cognitive or physical activities without interaction with the system. For instance, when end-users watch a video clip and decides which frames they are interested in for annotation, they are performing a user task.

Application tasks are completely activated and executed by the system. For example, detecting and displaying errors during compilation or during monitoring the network.

Figure 2.2. *The two possible presentations (shape or icon) of task types.*

Interaction tasks are invoked by the end-user and imply his or her interaction with the system.

For example, editing a document or phrasing a query to a database are interaction tasks.

Abstract tasks require complex actions and are classified as none of the above.

In a ConcurTaskTree task specification the types of tasks are presented differently either by icons or geometric figures (figure 2.2):

The task model is built in three phases. A tree-like structure is built using a hierarchical logical decomposition of the tasks. In each level of that tree, we identify the temporal relationships among tasks; for each layer, we identify the objects and the actions which allow them to communicate.

ConcurTaskTrees allow designers to describe concurrent tasks [PATERNO et al., 1997b], unlike GOMS [CARD et al, 1983], which uses hierarchical task decomposition to analyze sequential tasks only. Figure 2.3 shows a simple example of a task specified by ConcurTaskTree. We have a generic application during which the end-user can edit various possible modifications. Once a modification has been specified the end-user can either perform it or cancel it. In both cases, as editing is an iterative task, the end-user will be able to specify a new modification until the close task is performed.

Figure 2.3. *The Undo operation as a task specified in ConcurTaskTree.*

We may notice that ConcurTaskTrees are more formal than the UAN because they are more systematic, less ambiguous, and require more details to be specified in order to provide adequate task coverage.

2.1.3 The GOMS Model

In the GOMS model [CARD et al, 1983], the end-user's cognitive structure is composed of four elements: (1) a set of *Goals*, (2) a set of *Operators*, (3) a set of *Methods* in order to achieve the goals and (4) a set of *Selection* rules.

Goals: A goal describes the aim which the end-user wishes to do and it determines a set of methods needed to achieve that goal.

Operators: These are steps whose execution is necessary to change any aspect of the end-user's mental state or affect the task environment. However, a GOMS model does not support any fine structure of concurrency [CARD et al, 1983]. Behavior is described through the serial execution of operators. An operator is defined by its effect (output) and its duration.

Method: This is the procedure needed to achieve the goal. A method can be specified as a conditional sequence of goals and operators.

Control Structure (Selection Rules): In order to reach the desired goal, there might be more than one method available to the end-user. In the GOMS model, method selection is handled by a set of *selection rules*. Each selection rule is of the form "if condition is true in the current task situation, then use method M."

For example, in the process of building a text editor application:

GOAL: Del-All-Text

 CTRL-A-COMMAND

 DEL-COMMAND

Here, the *goal* is **Del-All-Text**, and the block defines the *method* to achieve it. Both **CTRL-A-COMMAND** and **DEL-COMMAND** are *operators*. Using this block structure, designers can create a hierarchy of end-user tasks.

The amount of detail generated in a GOMS description of an interface allows for thorough analysis. On the other hand, it can be a significant undertaking to produce.

2.1.4 The Task Knowledge Structure (TKS)

A Task Knowledge Structure (TKS) [Johnson et al., 1988] summarizes a end-user's task knowledge. This information guides the designers in making decisions about what knowledge possessed by the end-users will affect their interaction with the system and how a design solution might require the end-user to acquire more knowledge, or, conversely, to no longer require certain knowledge. In addition, such information about end-users' task knowledge will help to identify what should be supported, and what will cause problems and errors to occur, and so on. A TKS description is constructed by a member of the design team, who can be either an HCI specialist or a system designer.

The TKS requires the following knowledge components for a given task: roles, goals, subgoals, subtasks, plans, procedures, strategies, actions and objects. A *role* is assumed to be defined by a particular set of tasks that an individual is responsible for performing as part of their duty in a particular social context. A *goal* is assumed to be the state of affairs that a particular task can produce and forms part of a person's conceptualization of their task world while carrying out a given role. A *plan* is the particular formulation and possible ordering of subtasks that are undertaken to achieve a particular goal. A *procedure* is a particular element of behavior that forms part of a subtask.

Actions and objects are the lowest level of elements of tasks and are the constituents of procedures. The highest level of representation of the model is provided by the role/task

relations. The next level is the content of the TKS for a given task. This representation includes relations to lower level representations of the model containing the plan, procedures and taxonomic substructure (i.e., action and object property/feature lists). At a lower level of representation in the model is the plan and procedural knowledge associated with the specific task. This representation is referred to as a goal-oriented substructures. The plan represents the structure of the subgoals and the states which those subgoals satisfy. Where there is more than one alternative set of procedures these constitute different strategies. The procedures also have links to the taxonomic substructure, which is the lowest level of representation in the model.

2.1.5 Summary

From our survey, we can see that task models may vary in the following points:

- *Formalism:* The formality degree of one model varies from the other. For example, UAN descriptions may contain prose, while ConcurTaskTrees are very formal. The formality of the model governs the flexibility of processing it automatically. I.e., processing ConcurTaskTrees is easier than processing UAN.
- *Temporal Relationship:* Some task models (e.g., UAN and ConcurTaskTrees) support temporal relationships while others do not (e.g., GOMS).
- *Task Representation:* The task representation might vary from one model to another. For example, in the UAN, a task is represented by a UAN table, in the ConcurTaskTree as an object and in GOMS as a goal with its own block.

While we notice the following common features among them:

- *User Goal*: A task model starts by a goal to be achieved. The model describes how to achieve this goal from the end-users' perspective.
- *Task Coverage*: task models show whether all the intended system tasks are supported in a reasonable and consistent ways.
- *Hierarchical Tree*: Task models adopt the hierarchical tree representation to describe the decomposition of end-users' goal and the tasks needed to achieve this goal. This hierarchical tree may be in different presentations. For example, a ConcurTaskTree explicitly presents its model graphically, while GOMS uses indented blocks, or implicitly uses subtask references as with the UAN.
- *Tasks*: The basic element in any task model is the task.
- *HCI designers*: task models suit the HCI designers who might not be computer specialists, but instead artists, psychologists or experts in designing usable interfaces.
- *The Need for Computer-Based Tools*: most of the task models (e.g., UAN, ConcurTaskTrees, GOMS, TKS) can be tedious to produce if they are not supported by a computer-aided tool.

2.2 Architecture Models

Software engineers decompose complex systems into small parts using software architectures. This reduces the complexity of implementation, evolution and maintenance of the system [GRAHAM AND URNES, 1996].

The majority of architecture styles are based on the same separation of user interfaces and application seen in the Seeheim model [PEAFF et al., 1985]. However, where Seeheim proposes dividing the entire system into a single application and a single user interface, these styles divide the system into fine-grained subsystems, each with its own application and user interface component. Such architecture styles include: Model-View-Controller (MVC) [KRASNER AND POPE, 1988], Clock [GRAHAM AND URNES, 1996], Abstraction-Link-View [HILL et al., 1994], and PAC [CALVARY et al., 1997; COUTAZ, 1997].

Most of the architectural styles discussed here are supported by programming languages or toolkits and all have been used to develop interactive applications.

2.2.1 Model-View-Controller (MVC)

This architectural style was introduced in Smalltalk76 [KRASNER AND POPE, 1988] and has been implemented with minor variations in a wide range of user interfaces toolkits, most recently in Sun's Swing framework for Java [ECKSTEIN et al., 1998].

Figure 2.4. *The Model-View-Controller(MVC) architecture [KRASNER AND POPE, 1988].*

Figure 2.4 illustrates the structure of MVC. An MVC triad consists of a *model*, which represents the application's data; a *controller*, which interprets end-user input; and a *view*, which presents output.

The view and the controller can send updates and requests to the model. In response to state changes, the view presents a new output to reflect the new status of the model.

The key to the MVC's power is how these components communicate. The controller receives and handles the end-user inputs. It then determines how these inputs should be reflected as modifications to the model. The model then announces to the view that the model has changed. The view then updates itself, resulting in a new display for the output.

Figure 2.5. *The Abstraction-Link-View model (basic structure).*

This approach leads to a strong separation of concerns between the model, view and controller. The controller does not directly communicate with the view, only with the model. The view is responsible only for updating the display, and does not need to know the details of when display updates arise.

2.2.2 Abstraction-Link-View (ALV)

The Abstraction-Link-View architectural style (ALV, pronounced “al-vee”) [HILL, 1992] was developed at Bellcore, and is based on MVC. ALV consists of combined view-controller pairs (called *views*), separate hierarchies of views and abstractions (models), and a constraint mechanism called the *link* which connects the two. Abstractions and views are trees of objects; links are “bundles” of constraints. The ALV architecture style is shown in figure 2.5.

The major difference between ALV and MVC is ALV’s use of constraints instead of calls and events to connect the view and abstraction hierarchies. Neither abstraction nor view requires knowledge of the other because the constraints mediate all communication between them.

ALV constraints are completely declarative, removing much of the inherent complexity associated with callbacks [MYERS, 1991].

2.2.3 Clock

The Clock architecture style was designed to support the evolutionary design of architectures for interactive, multi-user systems [GRAHAM AND URNES, 1996]. The language provides the properties of *restricted scoping* to reduce direct dependencies among components, *automatic message routing via delegation*, and *easy modification of the hierarchical structures* of architectures. Clock is supported by the visual *ClockWorks* programming environment [GRAHAM et al., 1996a].

Figure 2.6 shows an excerpt of the Clock architecture for a selected program. A Clock

Figure 2.6. An excerpt of Clock architecture.

architecture consists of a tree of communicating components. Components may respond to end-user input (or input from other components), and may produce graphical output to be placed on the display. Components may also contain instances of abstract data types (*-ADTs*), such as the *CurrentColor* attached to the *userView* component. Each component has a name (e.g., *colorSelector*) and a class (e.g., *ColorSelector*).

Components communicate via interface messages: *input*, *request* and *update* messages. Messages are automatically routed up the tree to the nearest component capable of handling them. This routing mechanism provides a form of inheritance by delegation, where components inherit all the facilities of the components appearing above them in the tree. This communication mechanisms means that components can only access the data of components appearing above them – components may not directly communicate with their children or siblings.

2.2.4 Presentation-Abstraction-Control (PAC)

The Presentation-Abstraction-Control (PAC) architecture style [CALVARY et al., 1997; COUTAZ, 1997], decomposes a system into a hierarchy of PAC triads. Each triad includes a *presentation*, which is analogous to an MVC view-controller pair, and an *abstraction*, which is analogous to an MVC model. However, where MVC views and controllers communicate directly with their models, all communication in a PAC triad is mediated by the *control*. This has the key advantage that presentations and abstractions can be developed in isolation from one another, since any syntactic or semantic mismatches can be accommodated by the control. A PAC triad is shown in a figure 2.7.

Figure 2.7. A PAC hierarchy.

Figure 2.8. A PAC structure .

Figure 2.8 illustrates the structure of a typical PAC application. The hierarchy of PAC triads represents application composition. The root triad represents the application as a whole, and is decomposed (here) into two subcomponents, which might represent different windows of the application. These are in turn further decomposed until the level of individual interactive objects is reached.

In the same way that PAC controls mediate communication between their presentations and abstractions, they also mediate communication up and down the hierarchy. This keeps the presentations and abstractions simple, and allows the controls to appropriately update their presentations and abstractions in response to information arriving from higher to lower levels.

2.2.5 Summary

From this survey, we can summarize the common features among these architecture models in the following points:

- Most of the architecture styles have the powerful feature of the separation of input and output (inherited from the MVC model).
- Each architecture style is represented by a hierarchical tree of communicating components. However, component details may vary from one architecture style to another.
- Each architecture style has its own mechanism of automatic update of the display whenever the model changes (e.g., by *constraints* like Clock, *links* in ALV, or *events* in PAC).

2.3 Efforts to Bridge the Gap

In this section, we briefly describe some researches similar to our work in terms of exploring the theme of linking the behavioral domain the constructional one. Section 2.3.1 describes an approach in which the UAN model was transformed to Petri nets, giving formal meaning to the UAN. Section 2.3.2 describes a methodology by which architecture models can be derived from ConcurTaskTrees. Section 2.3.3 describes a complete environment (ADEPT) which

accepts a task model (TKS) as input and constructs a complete user interface out of it. Section 2.3.4 describes a framework in which multiple perspectives are maintained separately as distributed objects, called *ViewPoints*.

2.3.1 Transforming the UAN to Petri Nets

The goal of this work was to provide a gateway between *task* models defined with the UAN formalism and *system* models.

That was accomplished by giving formal Petri net equivalencies for every UAN construct [PALANQUE et al., 1995]. Petri nets are a mathematically founded formalism designed for modeling concurrent systems. When modeling with Petri nets, a system is described in terms of state variables (called *places*, depicted as ellipses) and by state-changing operators (called *transitions*, depicted as rectangles), connected by *arcs*. The state of the system is given by the *marking* of the net, which is a distribution of tokens in the net's places. State changes result from the firing of transitions, yielding a new distribution of tokens. Transition firing involves two steps: (1) tokens are removed from every input place, and (2) new tokens are deposited in every output place. A transition is enabled to fire when all of its input places contain tokens. Figure 2.9 depicts a small Petri net which illustrates the simple concept of sequences of actions.

Figure 2.9. Petri net representation for a sequence of tasks A and B described by the UAN notation.

Figure 2.10. Petri net representation for the UAN description of choosing between two tasks A or B.

Figure 2.10 indicates another relationship which is a choice between tasks when the end-user has to choose (equally) and perform one of these tasks.

One of the benefits gained from this work is resolving the ambiguities of task models during the translation process. This process, while automated to a certain extent, is interactive as it asks the designer of the tasks models to make their specification more precise if needed.

2.3.2 Engineering Task Models

Paterno and his colleagues [PATERNO et al., 1997a] described a method which allows designers and developers to define a task model of the interactive application considered and then to derive an architecture specification. The goal of the work was to obtain a systematic method that allows designers to derive architectural models from task models.

This work was based on the ConcurTaskTrees as a task model and on an architectural model which differs from other models for software interaction objects such as PAC or Myers' interactors [MYERS, 1990], as it structures each of them as an entity supporting bi-directional communication between users and software applications.

The work focused on identifying rules for transforming tasks to interactors. Once these rules have been precisely defined, they can be incorporated into a tool which supports the transformation of task models to architectures. However, this group believed that *this transformation cannot be done completely automatically* [PATERNO et al., 1997a].

This work resulted in an algorithm for transforming tasks to interactors. The algorithm identifies the interactors, identifies the connections among them, and makes the interactor comply with the temporal relationships defined at the task level.

2.3.3 ADEPT

To help designers refine their collective knowledge about tasks, a series of modeling tools have been developed as part of an Advanced Design Environment for Prototyping with Task Models - ADEPT [JOHNSON et al., 1993, WILSON et al., 1992, WILSON et al., 1993]. These modeling tools provide editors, browsers, and libraries, which ease the process of organizing the vast amount of information about the task.

The process of producing the computer version of the task models commences when the designers have constructed and agreed on the pencil-and-paper versions. The shift from paper to computer-based representations may come earlier or later depending upon how easily the designers and end-users feel that the different media of representation can allow them to develop their joint understanding of the tasks and the design problems.

During the end-users' and designers' development of the task models, it will become apparent that numerous task models will be required. There will be one task model for each task and there may also be an overview model, which shows how the different tasks are related. Editors allow the end-users and designers to rename, delete or replace an existing entry, add a procedure or a subgoal to the task model, and expand or contract the model in depth. At a further stage of development, objects can be edited and their properties changed. The objects are domain objects that are affected by or used in the particular task defined by the currently displayed task model.

The task modeling activity proceeds by developing the detail of the various tasks of the end-users to produce a series of task models represented in the task model library of the ADEPT toolset.

At this point, the end-user and the designer agree that it would be appropriate to begin to develop some design ideas and see how they fit into the activities.

The end-users are able to understand and contribute to the design discussions because the focus is on activities, tasks, and objects associated with taking end-user's activities. Consequently, as the design ideas progress, the designers and end-users return to the ADEPT tools and begin to transform the task model they have constructed into a design.

The designer begins to create a new version of the task model, which is called the "design task model." The design task model is a high-level specification of what the design will allow end-users *to do*. Thus, it is the first attempt at meeting the design requirements by saying what the computer system will enable end-users to do and how it will affect their work. From the design task model the designers and end-users can produce an Abstract Interface Model (AIM) using the ADEPT tools.

The AIM is a model of the interaction aspects of the proposed design. It takes the structure of the tasks as described in the design task model and instantiates that as the structure for the interaction dialog. The AIM provides a *use-case* model of the way the various objects of the design will be linked together and used during a particular interaction scenario. The object component of the AIM provides a complete description of all the objects necessary to support

the designed dialogs and to allow the designed tasks to be carried out. This is a textual description of the objects, their properties and links to other objects, including dialog links.

The AIM is developed further to produce a Concrete Interface Model (CIM), which provides a runnable version of an actual interface with which the end-users and the designers can interact. The method by which the CIM is developed is through refining the design to detail how the interaction described in the AIM is to be realized in an actual computer interface.

2.3.4 Viewpoints

This work describes an approach to the “multiple perspective” problem in software engineering - many actors, many representation schemes, diverse domain knowledge and different development strategies, all in the context of disturbed asynchronous development.

Traditional approaches to the problems of distributed work use a central database, or repository, to which all team members have communication access. Such centralized approaches do not adequately support the reality of distributed engineering [CUTKOSKY et al., 1993].

The alternative, a fully decentralized environment, is problematic because of the difficulties of maintaining the consistency between a large collection of agents. However, these problems can be overcome by recognizing that maintaining global consistency at all times is an unnecessary burden. That will maximize design freedom, and prevent premature commitment to design decisions. The focus therefore shifts from maintaining consistency to the management of inconsistencies.

The framework upon which this work is based supports distributed software engineering in which multiple perspectives are maintained separately as distributed objects, called *ViewPoints* [FINKELSTEIN et al., 1992]. A ViewPoint can be thought of as a combination of the idea of an 'actor', 'knowledge source', 'role' or 'agent' in the development process, and the idea of a 'view' or perspective that an actor maintains.

Relationships between ViewPoints are expressed by a set of *Consistency Rules* [EASTERBROOK et al., 1994]. The resolution process is concerned with establishing a relationship between two ViewPoints. Resolution only becomes necessary if consistency check failed, *and* the ViewPoint owner wishes to correct this. In many cases, resolution will not be necessary after the failure of a rule, because the inconsistency can be tolerated.

The goal of inconsistency resolution is to (re-)establish the relationships contained in the rule or rules which failed. If a relationship did previously hold, information about subsequent changes can be used to guide the resolution process. A prototype computer-based environment and associated tools (the *Viewer*) have been constructed to support this framework [NUSEIBEH AND FINKELSTEIN, 1992].

2.3.5 Summary

Transforming UAN descriptions to Petri nets (section 2.3.1) is a transition from the behavioral domain (represented by the UAN) to the constructional domain (represented by Petri nets). This transformation tightened the formalism of the UAN and increased the ability of processing it automatically. Unfortunately, this approach focused only on one aspect in the

UAN model which is the *user actions* column specifications. Further work is still needed to transform the entire UAN table (i.e., all its columns) to Petri nets.

Paterno's team (section 2.3.2) succeeded in making the transition from the behavioral domain (ConcurTaskTrees) to the implementation side (software architecture). This work can be used to both design and develop new systems but might not help to analyze existing ones. I.e., existing systems (represented by their design and implementation models) never stop evolving, leading to the need for a mechanism by which we can link existing models as they coevolve. That is our objective in this thesis as we aim to generate links between design artifacts which map one artifact to another.

The ADEPT tools (section 2.3.3) allow designers to start with a TKS task model, and go through several transformations until producing a final runnable model of the interface. Then, the result is a complete system. The disadvantages of this approach is that these tools are strictly dependent on the task model used (TKS); the final product is too constructional (not an architecture); and it is a one-way transformation, i.e., from the task model to the construction of the user interface.

Lastly, an important advantage of the ViewPoints approach is that it more accurately reflects actual work practices. Tolerance of inconsistency allows actions affecting more than one ViewPoint to be de-coupled. This facilitates distributed work by allowing responsibility to be devoted to individual ViewPoints.

We aim by our approach in this thesis to semi-automatically generate links between the UAN task model and the Clock architecture. We expect that the semi-automation approach will encourage designers to generate the links between the artifacts whenever they evolve.

The next chapter gives more details about the UAN and the Clock architecture models, and introduces the *Uista* tool which is used to visually browse the links between them.

Chapter 3

DESIGN ARTIFACTS BROWSED IN VISTA

The work done in the *Vista* tool [BROWN et al., 1998] motivates the research presented in this thesis. Vista showed that design artifacts developed to produce user-interfaces can represent radically different views of a system under development. The Vista tool was developed to help designers explore design artifacts through visual links relating these artifacts. Vista requires developers to manually specify links between design artifacts, motivating future research of investigating how links can be created and maintained in a more automatic manner. This thesis presents Adligo, a tool that semi-automatically generates links between design artifacts, represented in a form suitable for viewing in Vista

In this chapter we explain the different design artifacts supported by Vista, and show how they are linked together visually. We support our discussion by examples drawn from the *Critical Path Method (CPM) Planner* application [GRAHAM, 1997], which was developed independently of this project.

The chapter is organized as follows. Section 3.1 introduces the notion of task modeling. Section 3.2 describes the interface design of the example application, the CPM Planner. Section 3.3 gives a practical introduction for writing a task-oriented specification using the UAN notation. Section 3.4 describes the Clock architecture and some of its features. Section

3.5 presents the Vista tool and describes how it visually shows the links relating the UAN and the Clock architecture model.

3.1 Task Modeling: Task Hierarchy for Project Planning

Let us imagine that we are in the process of developing a system for project management. One of the methods used for this purpose is the Critical Path Method (CPM). Using this method, projects are decomposed into job steps. Dependencies among job steps are assigned by arranging them into a network (figure 3.2). Resources are allocated to the job steps. End-users may reallocate resources upon identifying the critical path in the network [GRAHAM et al., 1996b]. To describe how to manage a project, designers can use a *task model*. A task model is a design artifact resulting from the task analysis process [BERRY et al., 1997, DIAPER, 1989, JOHNSON et al., 1995].

A task model records the tasks that potential end-users of the system may need to perform to do their jobs, independent of dealing with a particular computer system. The design of an interactive system is based on supporting these tasks. Figure 3.1 shows the task hierarchy for the CPM Planner application. It describes how to carry out the task of planning a project. This figure shows how to decompose the main goal into subtasks that help achieve this goal. The root task of planning a project is split into the two subtasks of specifying the steps involved in the project and how they depend on each other, and of allocating resources to each step (This task is not supported by the program of figure 3.2). The task of specifying job steps and dependencies is solved via the task of creating a CPM network, which in turn consists of the

Figure 3.1. Task model for planning a project using the critical path method [GRAHAM et al., 1996-2].

subtasks of specifying the job steps, specifying their dependencies, and beautifying the presentation of the network.

3.2 User Interface Design: The CPM Planner Application

The previous section discussed the end-user tasks needed to plan a project. Figure 3.2 shows the user interface of the CPM Planner application, a groupware project management tool developed in the Clock language [GRAHAM AND URNES, 1996]. The CPM Planner allows participants to create nodes in a network. Nodes are connected by drawing a line from a source node to a destination node. Each node is assigned a sequential number. A control panel contains buttons for switching the mode of operation: repositioning, creating and connecting nodes.

Figure 3.2. A collaborative tool (the CPM Planner). Tore and Nick are using this application. They can connect, reposition, and add nodes. Each user can see the other's display [GRAHAM et al., 1996b].

The next section describes how we can use the UAN notation to write an accurate specification for such an interface.

3.3 Task-Oriented Specification Using the UAN

A task-oriented specification encodes how tasks are carried out with the user interface, from the point of view of the end-user. HCI designers use the UAN to encode their tasks in a tabular format.

Section 2.1.1 gave a brief description of the UAN. This section is a practical [HARTSON et al., 1990] rather than a theoretical introduction [SIOCHI AND HARTSON, 1989]. We first introduce the UAN through a simple example, then proceed to more complex examples illustrating the UAN's advanced features.

3.3.1 A Simple Example

Suppose that we want to describe a simple task such as selecting a mode of operation (e.g., repositioning, connecting, or adding nodes) in the CPM Planner application. In prose, this task can be described as follows:

- (1) Move the pointer to the desired mode button.
- (2) Depress and immediately release the mouse button.

The user action portion of the UAN description would be:

- (1) $\sim$ [mode]
- (2) $Mv^{\wedge}$

The $\sim$ denotes moving the pointer, in this example into the context of the mode button. The second line represents depressing (v) and releasing ($\wedge$) the mouse button (M).

Let us consider another example: the task of moving a node. We can state this in prose:

- (1) Move the pointer to that node. Depress and hold down the mouse button. By depressing the mouse button, the node is considered to be selected and accordingly its display is highlighted.

- (2) While holding down the mouse button, move the pointer.
- (3) Release the mouse button. The display of the node is now moved to the location where you released the button.

The user action portion in the UAN can describe this task as follows:

- (1) $\sim[\text{node}] Mv$
- (2) $\sim[x, y]$
- (3) $M^{\wedge}$

The first line means that we move the pointer into the context of the node and depress the mouse button. In the second line, $\sim[x, y]$ indicates movement of the pointer to an arbitrary point x, y in the network. The mouse button is released in the last line.

3.3.2 Interface Feedback

The previous section showed how to describe the user actions necessary for a task. If we compare the UAN description with the prose in the simple example discussed above, we find that the prose contains feedback and semantic information as well as the user actions. The *interface feedback* information represents the responses of the user interface to the actions carried out by the end-user.

Figure 3.3 shows a UAN table, which is read left to right, top to bottom. It indicates that when the end-user moves the pointer to the node and depresses the mouse button, the icon is highlighted (node!). As the end-user moves the pointer about the network, the highlighted node is displayed at that location. Finally, upon the release of the mouse button, the node is

TASK: Move a node	
USER ACTIONS	INTERFACE FEEDBACK
~[node] Mv	node!
~[x, y]	Display node! at x, y
M^	Display node at x, y

Figure 3.3. UAN description of the task "move a node" with interface feedback.

TASK: Select a mode	
USER ACTIONS	INTERFACE FEEDBACK
~[mode] Mv	mode-! : mode!, $\forall$ mode' ! : mode' -!
M^	

Figure 3.4. UAN description of the task "select a mode" (more precise feedback description.)

TASK: Select a mode		
USER ACTIONS	INTERFACE FEEDBACK	INTERFACE STATE
~[mode] Mv	mode-! : mode!, $\forall$ mode' ! : mode' -!	selected = mode
M^		

Figure 3.5. UAN description for the task "select a mode" with the interface state information.

displayed in the new position. Note the line-by-line association of feedback with the corresponding user actions. This level of precision is lost in the prose description, in which actions and feedback are mixed together. For instance, consider the task of selecting a mode:

- (1) Move the pointer to the desired mode button.
- (2) Click the mouse button and the button will be highlighted.

The UAN description for this task is shown in figure 3.4. The feedback means that whenever you select a mode button, all others are deselected. A highlighting action is applied to the icon

(model) only if the icon is not already highlighted; $\forall$ means “for all”, and a colon is used between the condition and the corresponding feedback.

3.3.3 Interface State

It may be necessary to include some state information both for the interface and for its *connection to computation*, associated with user actions. Figure 3.5 shows the interface state of the task “select a node”. The variable `select` is set to the new selected mode. As another example, figure 3.6 shows that depressing the mouse button when the pointer is over an object icon causes the object represented by that icon to be selected. If HCI designers are concerned about the location of the icon as a part of the computational component of the application, they can add the *connection to computation* column as shown in figure 3.6.

3.3.4 Context of Objects

The symbol $\sim[X]$ describes the end-user task of moving the cursor into the *context* of the interface object X. Moving out of the context of the same object is denoted by $[X]\sim$. The context of an object is the visual representation of the object on the display. For example, in the expression $\sim[X] Mv$, it is assumed that the pressing of the mouse button takes place within the context of X.

3.3.5 Summary

Section 3.3 gave an introduction of how to write a task-oriented specification using the UAN through some examples. The UAN descriptions are written in tables. A table may consist of

TASK: Move an object icon			
USER ACTIONS	INTERFACE FEEDBACK	INTERFACE STATE	CONNECTION TO COMPUTATION
~[object_icon] Mv	object_icon-! : object_icon!, $\forall$ object_icon'! : object_icon'-!	selected = object	
			location (object_icon) = (x, y)

Figure 3.6. UAN description of the task "move an object icon" with connection to computation information.

user actions, interface feedback, interface state and connection to computation columns. The UAN notation describes how the interface display and state respond to the user actions. The " $\sim$ [context]" denotes changing the context in which user actions take place. Identifying the UAN context is one of the key ideas used to generate the links semi-automatically as we will see in chapter 4.

3.4 Building the CPM Planner Using the Clock Architecture Style

Software engineers decompose complex systems into small parts using software architectures. This reduces the complexity of implementation, evolution and maintenance of the system [GRAHAM AND URNES, 1996].

Clock architecture style is an extension of the Model-View-Controller (MVC) paradigm [KRASNER AND POPE, 1988] (see section 2.2.1). MVC was designed to support the evolutionary design of architectures for interactive, multi-user systems. The Clock architecture style provides the properties of restricted scoping to reduce direct dependencies among components, automatic message routing via delegation, and easy modification of the

Figure 3.7. The CPM Planner Clock architecture. The Clock architecture is a tree of communicating components. The Depressed ADT is attached to the browseNode component.

hierarchical structure of architectures [GRAHAM AND URNES, 1996]. Clock is supported by the visual *ClockWorks* programming environment [GRAHAM et al., 1996a].

Figure 3.7 shows that the Clock architecture is a tree of communicating components. Components may process end-user inputs or inputs from other components. They may also produce graphical output on the display. Components can be augmented by abstract data types (ADT's), such as the *Depressed* ADT, which is attached to the *browseNode* component. Each component has a name (e.g., *browseNode*) and a class (e.g., *BrowseNodeView*).

Components may be grouped. Clicking a component's *open door* icon opens the group and reveals its internal structure. The *close door* icon elides detail. The *interface* of a component can be shown by toggling the component's interface icon. The *input*, *request* and *update* messages allow the components to communicate. For example, *haveLock* and *isDepressed* are requests; *setNodePosition* and *release* are updates; *mouseButton* and *relMotion* are input events (see figure 3.7). The arrows on the left side of the component indicate the messages the component may receive, while the arrows on the right side indicate the messages the component may issue. The method may be a *request* or an *update*. A *handler* is a method belonging to a specific component or an ADT.

Messages are automatically routed up the tree to the nearest component capable of handling them. This means that components can only access the data of components appearing above them - components may not directly communicate with their children or siblings [GRAHAM et al., 1996b].

The next sections describe two signification features in this architectural model: constraints and automatic routing.

3.4.1 Communication via Constraints

Restrictive scoping rules are imposed in the Clock architecture. Therefore, the ways in which components can directly communicate are reduced. In order to allow components to indirectly communicate, Clock embeds a constraint mechanism into its architecture language. These restrictions have the positive effect of reducing the number of direct dependencies among components, in turn reducing the impact of architectural change [GRAHAM et al., 1996b].

3.4.2 Automatic Routing

As the architecture evolves, it is common to add ADT's, split or combine components, and otherwise change the locations of where updates and requests are handled. In typical architecture descriptions, communication is bound to specific components; i.e., it is necessary to specify exactly where a method call is directed. This form of explicit targeting makes code less robust to change, since as components evolve, the method may no longer be handled by the same component. In Clock, requests and updates are automatically routed to the nearest component above the issuer of the message that is capable of handling it. This routing mechanism is only possible due to Clock's restricted visibility rules, which are in turn made possible by the use of constraints [GRAHAM et al., 1996b].

3.4.3 Summary

Section 3.4 introduced the second design artifact which is the Clock architecture model. The Clock architecture is a tree of communicating components. Components may be augmented by ADT's. Requests and updates are the interfaces of components and ADT's. Components can communicate via constraints. Such constraints create restricted visibility rules that make the automatic routing mechanism possible in this architecture style.

3.5 The Vista Tool

Vista is a prototype tool developed for examining the links between design artifacts [BROWN et al., 1998]. It allows the designers to simultaneously navigate hyperlinked task analysis, task-oriented specification, software architecture and code documents. We describe the features of

this tool through the CPM Planner. Visra uses the Clock architecture style for developing user interfaces [GRAHAM AND URNES, 1997].

Figure 3.8. Linked views in Vista. A designer has selected four views of the CPM Planner application: (a) the task hierarchy; (b) the task-oriented specification in the UAN; (c) the Clock architecture of the application, and (d) the Clock code. The Vista display has been manually annotated to show some of the links between the design representations.

3.5.1 Vista Puts Them All Together

Figure 3.8 shows four views of the CPM Planner as displayed in the *Vista* tool. The four panels are (a) the hierarchical task model, (b) the UAN task-oriented specification, (c) the Clock architecture and (d) the Clock code. These views show the design and implementation of the task “Reposition a Node”. The views of these four panels are connected by hyperlinks, so that when designers click on information in one panel, the corresponding information is shown in the others. Figure 3.8 has been annotated to show four of the hyperlinks available to designers. For example, clicking on the “Reposition a Node” task in panel (a) pops up the corresponding UAN table in panel (b) (link 1 in figure 3.8). Designers may tile the Vista display into one, two or four panels, allowing them to select between more views and bigger panels.

The next section describes the links between the task-oriented UAN specification and the system-centered Clock architecture specification. Links between other specifications are not as complex. The section explores how the UAN concepts elements *context*, *user action*, *interface feedback* and *interface state* are linked to the architectural elements of *components*, *input events*, *view methods* and *ADT's*.

3.5.2 Linking the UAN Contexts to Architecture Components

Clock architecture components implement the UAN contexts [BROWN et al., 1998]. For example, in the task “Reposition a Node” of figure 3.8, the UAN context *n* is implemented by the *nodeView* architecture component. In Vista, clicking on the *n* in the UAN table highlights the *nodeView* component in the architecture view.

Figure 3.9. UAN contexts n1, n2 and n3 are implemented by the architecture component "nodeView."

Identifying which architecture component implements each UAN context is non-trivial [BROWN et al., 1998]. The HCI designer and the software engineer may have given the same entity a different name (as in the example above). Another problem is that the relationship between the UAN contexts and architecture components is not one-to-one. Architecture designers do not necessarily create a new component whenever the UAN specification identifies a new context. Figure 3.9 shows how one architecture component can implement more than one UAN context. The UAN contexts *n1*, *n2* and *n3* are implemented by the *nodeView* component. Providing a solution for such problems is the core of this thesis (see chapter 4: Semi-Automated Link Generation Process.)

3.5.3 Linking the UAN Actions to Architecture Components

In the UAN descriptions, user actions specify what inputs end-users perform in order to perform their task. User actions occur within contexts. For example, in order to move a node to another location (after switching to the repositioning mode), the end-user positions his or her pointer over that node ($\sim[n]$) in the *nodeView* view and then depresses the mouse button (Mv). Therefore, the action “Mv” occurs in the context of *nodeView*. User actions are processed by the architecture components implementing the action context. Since *nodeView* implements the context *n*, it also processes the user action “Mv” in the method *mouseButton*, whose prototype is shown in figure 3.8(d).

Accordingly, user actions are linked to the components that implement those actions. Clicking on the “Mv” symbol in figure 3.8(b) displays the method that handles mouse button events (link 3), and highlights the component that contains the method (link 4).

3.5.4 Linking the UAN Interface Feedback Specifications to Component Views

The *interface feedback* column in a UAN table specifies how the display should change in response to end-user input. The software engineer uses this information to implement the *view* methods of architecture components. In the CPM planner, clicking the “n!” or “n-!” text in figure 3.8(a) highlights the *nodeView* component of figure 3.8(b) which implements the appearance of the node.

3.5.5 Linking the UAN User Interface State to ADT's

User actions can cause displays to change but they can also trigger state changes. In the UAN, these state changes are specified using pseudo-code in the *Interface-state* column of the UAN table. In Clock architectures, states are implemented as abstract data types (ADT's), which are attached to architecture components. The state that is referenced in the pseudo-code of the UAN tables can then be linked to the ADT's implementing the state.

For example, in figure 3.8(b), the UAN specifies that clicking on one of the nodes (after switching to the repositioning mode) should lock that node “Lock n”. As the end-user moves the node around the screen, the node position is updated accordingly “nodePosition(n) := (x, y)”. Once the end-user releases the mouse button, the locking is released “unlock n”. The locking/unlocking mechanism is implemented using the *Lock* ADT, which is attached to the *root* component (not shown in figure 3.8). Information about the node position in the network is stored in the *NodePositions* ADT, which is also attached to the *root* component. *Vista* displays the links between interface state and ADT's. For example, clicking on the “Lock n” or “unlock

n” texts in figure 3.8(b) highlights the *Lock* ADT while clicking on the “nodePosition(n) := (x, y)” text highlights the *NodePositions* ADT.

3.6 Summary

The goal of this chapter was to describe the two design artifacts, the UAN and the Clock architecture models, and show how to browse the hyperlinks relating them in the Vista tool. Most of the examples were derived from the CPM Planner application.

The chapter started by describing the task modeling and task-oriented specifications using the UAN. It gave a simple practical introduction for the UAN notation and its tables. The Clock architecture was described as a tree of communicating components. This architecture style is featured by the automatic routing mechanism, which is possible due to the Clock’s restricted visibility rules. Lastly, we described the Vista tool, which is used to examine the hyperlinks relating the UAN and the Clock architecture models.

However, Vista. has some major problems. Links in Vista are hard-coded and manually specified. We may need to feed hundreds of links manually to Vista in order to relate the UAN and the Clock architecture models of a medium size case study (see chapter 6: Experiments and Analysis). The problem gets more challenging if we wish to maintain these links as the design artifacts evolve. In this case, the link generation process is necessarily iterative in order to maintain the relationship between the two design artifacts. Chapters 4 and 5 of this thesis describe how we provide a semi-automatic solution for such problems.

Chapter 4

SEMI-AUTOMATED LINK GENERATION PROCESS: THE *ADLIGO* TOOL

In this chapter we introduce *Adligo*, a tool demonstrating the semi-automated process for linking two user interface design artifacts: the UAN task model and the Clock architecture. *Adligo* has built-in knowledge of the two artifacts to be linked. As shown in chapter 6, Experiments and Analysis, this knowledge is not sufficient to derive a reasonably complete set of links. Therefore, a human familiar with the artifacts to be linked must provide additional information to enable *Adligo* to produce a highly accurate set of links.

We provide in this chapter a full description of the link generation process for potential users of *Adligo*. Implementation details are left for chapter 5, while the tool evaluation is the subject of chapter 6.

The chapter is organized as follows. Section 4.1 presents the general framework of the link generation process. Section 4.2 presents a tutorial showing how *Adligo* is used to generate links. The tutorial shows how the links are derived for the different UAN columns, and introduces the dictionary and the pattern language supporting this process. Section 4.3

discusses more details, such as the UAN context, subtask referencing, dictionary types, the order of the rules in the dictionary, and more details about the pattern language.

Figure 4.1. A framework for generating links between task and architectural models in semi-automated fashion.

4.1 The Framework of the Link Generation Process

Figure 4.1 shows the framework of the process of generating links between the design and implementation of interactive systems. A UAN editor is used to write the task-oriented specifications, and to generate the UAN description as a text file suitable for input to Adligo. Since such an editor has not yet been implemented, this input file is currently prepared manually. The format of this file is described in appendix E. Programmers can write their programs in the Clock language using the *ClockWorks* visual programming environment [GRAHAM et al., 1996a]. This tool writes the architecture of the application in a textual format [GRAHAM, 1996] that can be fed into Adligo automatically. Finally, the designer provides a set of rules in a dictionary file. The dictionary is described in section 4.2.3.

Adligo accepts those input files, analyzes the semantics of each design artifact (i.e. the UAN and the Clock architecture models) and derives links between them. This process is carried out with the assistance of the dictionary rules. The result of running Adligo is a set of links which connect the two notations. These links are written in text files which can be used as input to the *Vista* tool, allowing the links to be browsed graphically.

Figure 4.2. A simple Clock application, the Counter. A number is displayed in a window. This number is incremented when a user clicks it.

TASK Increment Number		
USER ACTIONS	INTERFACE STATE	INTERFACE FEEDBACK
~[CountView] Mv	Count += 1	Display Count
M^		

Figure 4.3. The UAN description of the Counter application.

Figure 4.4. Clock architecture of the Counter application.

The tutorial in the next section uses a simple *Counter* application (figure 4.2), which displays an integer number in a window; whenever the end-user clicks this number, it is incremented. Figure 4.3 shows a UAN specification which records what actions a end-user must perform to increment the integer number. Figure 4.4 shows the Clock architecture for the Counter application.

4.2 Tutorial Introduction

In order to illustrate the concepts and steps involved in the link generation process, we present a simple tutorial which shows how to link the UAN model and the Clock architecture for a small application like the Counter. Figure 4.5 shows the links which the HCI and software engineers expect to see between the UAN and the Clock architecture models of the Counter. The tutorial will show how we derived these links with Adligo.

Throughout our discussion, we will be exposed to several concepts related to the link generation process. Section 4.2.1 explains how we derived the links for the user actions column. Section 4.2.2 shows the importance of identifying the context component in links inference. Section 4.2.3 introduces the dictionary as a translation means. Section 4.3.4 introduces some new terms related to searching the Clock architecture, such as the *scope*, the *context component* and the *current scope*. Section 4.2.5 shows the derivation of a link for the first user action in the Counter application. Section 4.2.6 shows that Adligo has some built-in knowledge, which helps in the link derivation process. Section 4.2.7 explains how to generate links for the UAN description residing in the *interface state* column. Section 4.2.8 introduces the pattern language used in writing the dictionary rules. Section 4.2.9 explains how to generate links for the UAN description residing in the *interface feedback* column. By the end of section 4.2.9, all the links for the Counter application are generated, and most of the concepts underlying Adligo are discussed.

Figure 4.5. The generated links between the UAN and the Clock architecture of the Counter application.

Rule#	DICTIONARY		
	RULE SCOPE	UAN PATTERN	CLOCK ARCHITECTURE PATTERN
1		Mv	mouseButton
2		M^	mouseButton
3		\$(var1)+=1	inc\$(var1) increment\$(var1)

Figure 4.6. The dictionary used for the Counter application.

Our starting point in this tutorial will be from the UAN table shown in figure 4.5, trying to map every *match* to its counterpart *handler* in the Clock architecture. A *match* can be any sequence of tokens that can be matched by a rule in the dictionary. A *handler* is a method inside a component or an ADT in the Clock architecture. The process iterates over every table in the task model.

The navigation inside the UAN table conforms to the direction of reading it: left to right, top to bottom. The Counter has only one task represented by one UAN table shown in figure 4.3. In the following sections, we will derive the links for this table.

4.2.1 Linking the User Actions

The first description in the *user actions* column is “~[CountView]”, which means that the end-user moves his or her mouse pointer to the Counter view. From the other columns of the task description, we can see that nothing happens as a result of this action. We should not expect to find any handler in the architecture because that action does not need any particular manipulation. Nevertheless, this action is crucial because it changes the context in which the subsequent actions take place. This means that any future events (or actions) will be intercepted and handled by *CountView* because it is the current context.

4.2.2 The Secret Is in the *Context*

A *context* in the UAN description is the object to which the end-user moves. Changing the context is denoted by the UAN notation “~[*context*]”. Any UAN context should be represented by a component in the Clock architecture. Therefore, we should search for a component named *CountView*. Since there is only one component in this hierarchy, the search process is trivial in this example (see figure 4.4). From now on, we have to keep in mind that our current context has been switched to *CountView*.

The next action is “Mv”, which means depressing the mouse button. In the Clock architecture, this event is handled by the *CountView* component via the predefined method *mouseButton*. Thereby, we have found a link between the UAN description “Mv” and the handler *CountView.mouseButton*.

The analysis of the decision that has led to this association is as follows: *CountView* is the component that represents the current context of user actions. Accordingly, it should contain a method that handles the user action denoted by “Mv”. We know (as humans) that the notation “Mv” and “M^” mean a mouse button depressed and released respectively. Therefore, the correct method (in Clock) to handle such events is the predefined method *mouseButton*. Such human knowledge needs to be fed to the Adligo tool in order to generate such links.

4.2.3 A Translator Is Needed: The Dictionary

The need to supply Adligo with some human knowledge motivated the introduction of the *dictionary*. A *dictionary* is a set of rules that translates the UAN notations to Clock architecture symbols (figure 4.6). As shown, the dictionary is a simple table composed of three columns:

rule scope, *U-1N pattern* and *Clock architecture pattern*. The table has a set of rows or entries called *rules*.

The *rule scope* column determines the scope of application of that rule in the task model. The rule can be *local* (i.e., applicable only to a specific task), or *global* (i.e., applicable to all tasks). To flag a rule as local to certain task, the task name can be written in the *rule scope* slot of that rule. Leaving that slot blank makes that rule globally applicable to any task in the model.

The *U-1N pattern* column contains a UAN description pattern written in a simple pattern language. Section 4.3.8 describes this language in detail. During the process of generating the links, Adligo tries to find a match in the UAN description using this UAN pattern.

If there is a match, the *Clock architecture pattern* column will be considered. This column contains another pattern that describes a potential handler in the architecture. Adligo searches the Clock architecture for this handler and if it is found, a new link is created.

4.2.4 Searching the Clock Architecture

Once a handler has been identified as the potential target of a link, Adligo tries to find the *first* occurrence of that handler within the *scope* of the *context component*. The *scope* of a component is the chain of components that starts from that component and goes upward until reaching the root of the architecture tree. The *context component* is the Clock architecture component that represents the UAN context. The *current scope* is the scope of the *context component*.

4.2.5 Deriving the Link for “Mv”

The next user action in the *Increment Number* task is “Mv”. If we search the dictionary (see figure 4.6) top to the bottom, we will find that rule #1 helps us derive such a link because “Mv” matches the UAN pattern in that rule. Consequently, we proceed to search the Clock architecture for the Clock pattern “mouseButton”.

4.2.6 Adligo Has Some Built-In Knowledge about the Models

The pattern “mouseButton” does not fully specify a handler since it shows the required method but does not specify its container (i.e., a component or an ADT). Adligo does not require the fully qualified name (the method and its container) of the handler because it knows that any user action must be handled by a component in the current scope. Accordingly, Adligo locates the *mouseButton* method in the *CountView* component, because it is the first component in the *current scope* that has the *mouseButton* method.

Figure 4.5 shows the link between the UAN notation “Mv” and the Clock architecture handler *CountView.mouseButton*.

4.2.7 Linking the Interface State

The next column is the *interface state* column, in which the designer expresses the idea of incrementing the stored number by the pseudo-code “count+=1”. This pseudo code is matched by rule #3 of the dictionary (figure 4.6). The UAN pattern “\$(var1) +=1” embeds a variable denoted by “\$(var1)”. Since the pattern may contain more than one variable, var1 is a unique identifier name for that variable. The variable “\$(var1)” is a *placeholder* for the token which precedes the string “+=1”. During the matching process, the variable “\$(var1)” is

bound to the token string which comes before the token sequence “+=1”. In our example, “\$(var1)” is evaluated to be “count” as a result of matching the UAN description “count +=1”.

The corresponding Clock architecture pattern of rule #3 is “inc\$(var1) | increment\$(var1)”. This pattern gives Adligo a choice of either of two possible methods as the handler for “count +=1”. The next section explains how these method names are derived from the corresponding UAN description.

4.2.8 The Pattern Language Usage

As a simpler example, assume that the provided Clock architecture pattern is “inc\$(var1)”, which is syntactically similar to the UAN pattern discussed above. Here, the variable “\$(var1)” is a reference to the variable used in the UAN pattern “\$(var1) +=1”. The Clock architecture pattern therefore evaluates to “incCount”.

Next, *Adligo* searches the *current scope* for this candidate method, *incCount*. Surprisingly, the result of this search is nil; i.e., there is no such method name in that scope. In rule #3, the designer has in fact provided two alternatives: “ inc\$(var1) | increment\$(var1)”. The symbol “|” means OR, allowing the dictionary rule to provide multiple target handlers. Since the last search failed to find a method named *incCount*, Adligo will automatically consider the next alternative, which is *incrementCount*.

The UAN match “count +=1” has been written under the *interface state* column. Using a built-in rule, Adligo realizes that such a match should be handled by the *highest* ADT in the *current*

scope that has that member method. This rule leads Adligo to link the “count +=1” match to the architecture handler *Count.incrementCount* (see figure 4.5).

4.2.9 Linking Interface Feedback

The third column in the UAN table is *interface feedback*. This column contains the prose “Display Count”. All the dictionary rules fail to find a match within this description. Nevertheless, the fact that this description falls in the *user interface feedback* column means the text specifies the system’s output. Every component in the architecture has a *view* method that specifies its display. Since the current context component is still *CountView*, then any UAN description in the *interface feedback* column will be mapped to the *view* method of the *CountView* component. Note that the *view* method is not shown in the architecture hierarchy (see figure 4.5).

Eventually, in the user actions of the second line, we encounter the action of releasing the mouse button “M^”. Generating the link for this action is the same as “Mv”, but this time rule #2 is used for matching rather than rule #1. At this point, the entire table has been mapped. If there were more tables in the model, each would be processed.

4.3 Link Generation Process: More Details

This section highlights some concepts which Adligo users should be aware of. Section 4.3.1 shows how it is important to identify the context in the UAN table, and section 4.3.2 shows how a subtask referencing might change that context implicitly. Section 4.3.3 explains the three logical classifications of the dictionary. Section 4.3.4 discusses the importance of the order in

which the rules appear in the dictionary. Sections 4.3.4 to 4.3.8 are concerned with the pattern language syntax and semantic.

4.3.1 Changing the UAN Context

The context change action, denoted by “~[*context*]” is crucial to the link generation process because that action means that *context* has gained the focus and has become responsible for handling the subsequent user actions. If we can find a component named *context* in the architecture hierarchy, that component must be in charge of intercepting and handling all the subsequent user actions.

The UAN task model and the Clock architecture model are typically produced by different people. Therefore, an object named *abc* in the UAN description might exist in the Clock architecture but with a different name *xyz*. Thus, Adligo needs a translation mechanism for determining that *abc* in the UAN notation means *xyz* in the Clock architecture. The dictionary does this translation.

For example, figure 4.7 shows the description of the task *Reposition a Node*. The HCI designer chose the name “n” to express the node being moved, while in the Clock architecture, we find that the node is called *nodeView*. Rule #6 in the CPM Planner dictionary provides this translation (appendix B).

Reposition a node	n	nodeView → browseNode
-------------------	---	-----------------------

As soon as Adligo recognizes the component that represents the UAN context, it will be able to derive the links for the UAN user actions. Adligo searches the architecture for the first handler for that user action in the *current scope*. Accordingly, Adligo realizes that “Mv” and “M^” are handled by the handler *browseNode.mouseButton* and “~[x, y]” by *browseNode.relMotion*. Notice that *browseNode* is not the context component, but lies in the *scope* of the current context component *nodeView*.

This routing rule can be extended to the *interface state* and *connection to computation* columns in a UAN table. These columns contain the UAN descriptions most likely querying or changing the system’s data. Such operations are handled by the architecture ADT’s, which are located in the *scope* of the context component. For example, in figure 4.8, “lock n” in the *interface state* column is mapped to *Lock.lock* (by applying rule #22 in appendix A – Standard Dictionary)

	lock	lock
--	------	------

and “nodePos(n) :=” is mapped to *NodePositions.setNodePosition* (by applying rule #9 in appendix B).

	nodePos(n):=	SetNodePosition
--	--------------	-----------------

The UAN description in the *interface feedback* column describes how the system’s display changes as a response to the user actions. In chapter 3, we mentioned that Clock architecture is among those modern architecture styles that separate the input from the output, and that it has the purely specification *view* method that draws the component’s display. This leads

TASK: Reposition a node		
USER ACTIONS	INTERFACE FEEDBACK	INTERFACE STATE
select mode (move)		
{ ~[n] Mv	lock n	n! n locked
(~[x,y]	nodePos(n) := (x,y)	display n at (x,y) on all users' displays, moving all connected lines and rubber-band lines.
) * M^	unlock n	n -! n unlocked

Figure 4.7. The figure shows the UAN table of the Reposition a Node task and the Clock architecture of the CPM Planner. The dictionary translates the UAN context “n” to the “nodeView” component.

Adligo to the fact that the UAN description in the *interface feedback* column should be mapped to the *view* method of the context component. For example, “n!”, “n locked”, “n-!”, “n unlocked” are all mapped to the handler *nodeView.view* (see figure 4.8). Nevertheless, some exceptions for this rule may exist, as explained in section 4.3.6.

4.3.2 Subtask Referencing in a UAN Table

A subtask can be referenced in the *user actions* column. “Select Mode (Move)” in figure 4.7 is an example of a subtask reference. Subtasks are treated as macros. The expanded task may contain user actions that change the context. Therefore, we have to make sure what is the current context at the end of that task. This is important because that context will become the context of the user actions immediately following that task reference. Fortunately, the “Select Mode (Move)” expansion in figure 4.7 is not critical in this UAN table because it is immediately followed by the action “~[n]” which changes the context. Therefore, ignoring it will not cause any mistakes.

To guide Adligo to how a specific subtask affects the context, we write a rule in the dictionary that has the task name as the *UAN pattern*, and the name of the context component as the Clock architecture pattern.

4.3.3 Dictionary Types

In practice, the dictionary is represented as a single text file. Logically, we classify the dictionary into three parts:

1. The *Application-Specific* dictionary consists of rules that are specific to an application under study. Appendices B and C are examples of this dictionary type.

Figure 4.8. Some links that connect the "Reposition a Node" task to the CPM Planner architecture.

2. The *Component-Specific* dictionary consists of rules that are usually needed whenever a certain architecture component is used.
3. The *Standard* dictionary consists of rules that map the commonly used UAN notations to the predefined methods in Clock architecture. These rules are generic enough to be applied to any case study (see appendix A).

For simplicity, Adlgo currently accepts one text file as a dictionary that contains the application-specific, the component-specific, and the standard dictionaries respectively. However, the implementation of Adlgo could be enhanced by making Adlgo include separate files of dictionaries, in a similar way to including header files in the C++ language or importing packages in Java.

4.3.4 Searching the Dictionary

The dictionary is sequentially searched from top to bottom. The first matchable rule is selected and used to derive a link. This allows some rules to overwrite others already there.

For example, “currentMode := mode” in figure 4.9 shows that the match “currentMode :=” is linked to *Mode.setMode*. Rule #10 in appendix B helped to generate this link correctly.

	currentMode :=	setMode
--	----------------	---------

If this application-specific rule were not added, this matching could be possible by rule #28

	\$(anyVar) :=	set\$(anyVar)
--	---------------	---------------

Figure 4.9. “currentMode :=” is linked to Mode.setMode.

in the standard dictionary (see appendix A), but that match would lead to the composition of a non-existing method name “setCurrentMode”, which means no link would be generated. Therefore, the order in which the rule appears in the dictionary is sometimes significant.

4.3.5 Using Variables in Patterns

The simplest pattern in this language is a string literal, which is used in rules translating a UAN context name to a Clock component name (see rules #3 and #4 in appendix B).

	n1	nodeView->connectNode
	n2	nodeView->connectNode

A pattern may contain one or more variables. The variable takes the form of \$(variableName). The variableName is a unique identifier, used for later reference. The meaning of the variable is dependent on whether it is part of a UAN pattern or a Clock architecture pattern. If the variable is part of the UAN pattern, then it plays the role of a *placeholder*. The value of the variable is bound during a successful match with a UAN description. The value of this variable is the string that composes or completes a token in the pattern. If the variable is part of the Clock architecture pattern, then it should have been used before in the UAN pattern. The value of this variable is substituted inside the Clock architecture pattern to form a string literal (see section 4.2.8 for a complete example).

Rule #12 in appendix B shows that it is not necessary to reference the UAN pattern variables in the Clock architecture pattern.

	Connect \$(obj1) to \$(obj2)	setConnectionTarget
--	------------------------------	---------------------

Such variables are used as dummy placeholders, but they are still important to the formation of such a generic rule.

4.3.6 Handler Names

We can write a rule which explicitly specifies a link, i.e., a rule which maps a UAN pattern to a particular Clock architecture handler. Syntactically, using the operator “.”, we can write the handler name as `componentName.method` or `ADTName.method` in the Clock architecture pattern.

For example, in the *Reposition a Node* task (figure 4.8), we show that some feedback matches such as “n!”, “n unlocked”, and “n-!” are linked to the handler *nodeView.view*, where *nodeView* represents the context component. This intuitive mapping does not apply to “lines” and “rubber-band lines” in the second line of the table. That is because the correct mapping of “lines” is to *edge.view* and “rubber-band lines” to *rubberband.view* (figure 4.8). We use the dictionary rules #13 and #14 to explicitly map such matches correctly.

	lines	edge.View
	rubber-band	rubberBand.view

4.3.7 Chained Component Names

Two components in the Clock architecture are allowed to have the same name if they are in different scopes. This might cause a problem for Adligo in determining which component to choose during the search process. Such ambiguity was also present in the *Reposition a Node* task as we translate the UAN context “n” to *nodeView*. But as shown in figure 4.7, the Clock architecture has two components named *nodeView*.

To resolve this ambiguity, we specify as many parents of the intended component as necessary to remove the ambiguity. The pattern language has the operator “→” which specifies the

component's parent. The component name may appear in the pattern as a chain, which looks like

$$\text{comp} \rightarrow \text{parent}_1 \rightarrow \text{parent}_2 \rightarrow \dots \rightarrow \text{parent}_n$$

Rules #6 and #3 in appendix B are examples of this syntax.

Reposition a node	n	nodeView->browseNode
	n1	nodeView->connectNode

4.3.8 Alternatives in the Clock Architecture Pattern

The pattern language has the operator “|” that means OR, allowing the dictionary rule to provide multiple target handlers as alternatives in the Clock architecture pattern (see Rule #6 in appendix A).

	~[\$(obj1), \$(obj2)]	motion relMotion
--	-----------------------	--------------------

Adligo considers one alternative after another during its search. Upon finding the first instance of any alternative, Adligo creates a link. For example, linking the UAN match “~[x, y]” was possible by using rule #6 whose Clock architecture pattern is “motion | relMotion”. This match was linked to *browseNode.relMotion* because it is lower than *MousePosition.motion* in the current scope (see figure 4.8).

4.3.9 About the Design of the Pattern Language

Simplicity and ease of use were the top concerns in the design of the pattern language (see the its grammar in appendix D). This language has just one type of variables, and three operators (“|”, “→”, and “.”). For the sake of ease of use, we avoided to use two different notations of using variables (see section 4.3.5) in the UAN and the Clock architecture patterns. In addition, this notation “\$(var)” is inspired by the notation used to write variables in the Make files of the UNIX operating system.

As discussed in chapter 6, Experiments and Analysis, we found this pattern language adequately flexible to write dictionary rules that generate high accurate links. We could obtain a large percentage of links (90%) by writing small number (8) of simple rules. The pattern language was efficient enough to write advanced rules to get 99% of the available links.

4.4 Summary

This chapter provides Adligo users with a full description of the link generation process. It starts by giving a general description of the framework of this process. It then shows where the Adligo tool fits into this frame, and what inputs should be submitted to it.

The second part of the chapter helps the user to understand how to generate the links systematically by following a simple tutorial. The tutorial provides a complete explanation for deriving all the links of a simple case study. This tutorial also introduces some aspects related to the link generation process such as the importance of the UAN context in link inference,

the scoping rules in the Clock architecture, Adligo's built-in knowledge, and the pattern language.

The third part of the chapter proceeds in providing more details about the role of the UAN context in deriving most of the links. It shows how some subtask references can alter the UAN context. This part presents the three logical classifications of the dictionary: application-specific, component-based, and standard. It also shows how the order of the rules inside the dictionary can affect the correctness of the generated links. The syntactic and semantic details of the pattern language are discussed such as using variables embedded in the pattern, specifying handler names, and the need for the chained component names. Finally, a simple analysis is given about the design for the pattern language and its usage.

Chapter 5

LOOKING UNDER THE HOOD: THE IMPLEMENTATION OF *ADLIGO*

Chapter 4 gave Adligo users a detailed description of the link generation process. It presented a simple tutorial for deriving links between the UAN and the Clock architecture models. Since the presentation in that chapter targeted Adligo users, no implementation details were discussed. This chapter presents implementation details of Adligo.

Section 5.1 provides a technical description of the framework of the link generation process and defines the basic data types and mathematical notations used in the rest of the chapter. Section 5.2 describes the dictionary functions. Section 5.3 describes the message routing rules of the Clock architecture style. In section 5.4, we describe how Adligo derives links for the UAN *user actions* column. In section 5.5, we describe how Adligo derives links for the UAN *interface state* and *connection to computation* columns, while in section 5.6 we describe the link generation algorithms for the UAN interface feedback column.

Figure 5.1. The high-level design of the link generation process using the Adligo tool.

5.1 The Framework of the Link Generation Process

As shown in figure 5.1, the link generation process requires three inputs: the UAN model, the Clock architecture model, and the dictionary. The output is a set of links that map elements of each model to the other.

At present, we write the UAN model manually in a text file because we do not have a UAN editor. Appendix E describes the grammar we use to write the UAN notation in that file. Since we use the visual programming environment *ClockWorks* [GRAHAM et al., 1996a] to write our Clock programs, the Clock architecture is easily obtained from ClockWorks as a text file. Each line written in this file describes a component in the architecture or the relationship between components in the hierarchy. Appendix F specifies the grammar used to parse this file.

Both the UAN and the Clock architecture models are fed into the Adligo tool. Adligo has a parser for each model that produces the parse tree. The two parse trees are input to the Adligo's internal module, the *link generator*, to establish the links between the two trees.

The link generator traverses the UAN parse tree, trying to generate a link for every UAN *match*. A UAN match is any sequence of tokens in the UAN description that can be matched by a dictionary rule, and therefore mapped to the Clock architecture. The direction of processing inside a UAN table is the same as the way it is read: top to bottom, left to right.

The UAN columns are processed in the following order: *user actions*, *interface state*, *interface feedback* and finally *connection to computation*. In order to find a match, all the UAN symbols inside

the table are parsed as tokens. A *token* can be a number (a sequence of digits), a string literal (a sequence of letters), or any other symbol. We define a token using the regular expression:

Token ::= (digit)*

Token ::= letter(digit|letter)*

Token ::= symbol

where *digit* is any one of 0, 1, 2, 3, 4, 5, 6, 7, 8 or 9, *letter* is any alphabetic character (any one of a-z or A-Z) or *_* (underscore), and *symbol* is any keyboard character which is not a *digit* nor *letter*.

To describe how Adligo identifies a UAN match and maps it to a Clock architecture handler, we use the notation $\langle t \rangle$ to define a *sequence* of type *t*. If *ts* is a sequence of tokens inside one of the UAN columns, the link generator searches the dictionary rules sequentially, top to bottom, to find a rule whose UAN pattern tokens (*ts'*) can match any subsequence in *ts*. (Notice that the UAN pattern of every rule is also parsed into a sequence of tokens *ts'*.) As soon as that match is found, the matched tokens in *ts* become a UAN match, and the link generator gets its translation from the Clock architecture pattern column. This UAN match may be linked to an architecture handler. Searching for more UAN matches among the unmatched UAN tokens of *ts* continues until all the dictionary rules fail to get a match.

Figure 5.2 provides a simplified description of the process of generating a link between the UAN model and the Clock architecture. Adligo translates a UAN context to a context component by looking up the dictionary. A UAN match is translated to a set of candidate

Figure 5.2. Generating a link between a UAN match and a Clock architecture handler. Using the dictionary, Adligo translates a UAN context to a context component, and a UAN match to a set of candidate methods. To find the correct handler, Adligo uses the routing rules of the Clock architecture style.

methods through the dictionary function D . The routing rules of the Clock architecture style use this set of candidate methods and the context component to find the correct handler in the Clock architecture.

In subsequent sections, we describe how Adligo generates links for the different UAN columns. Whenever appropriate, we support our discussion by mathematical notation to describe the algorithm accurately. Thus, we need to define common types which are used in later discussion.

Context represents the set of UAN contexts; **Component** represents the set of components in the Clock architecture; **ADT** represents the set of ADT's in that architecture, and **Method** represents the set of *update* and *request* events which a component or an ADT may receive. A link maps a UAN match to a Clock architecture handler. We define a match as a sequence of tokens:

Match == <Token>

and a handler as a method inside a component or ADT:

Handler == (ComponentOrADT × Method)

where ComponentOrADT == Component $\cup$ ADT.

(Figure 5.3 illustrates the meaning of some terms.) Accordingly, we define links as a relation between matches and handlers:

Link == (Match × Handler)

5.2 The Dictionary Functions

In this section, we define the dictionary functions, which we use in subsequent sections to

Figure 5.3. In UAN, a Context appears in the notation $\sim[\text{Context}]$. In this Clock architecture, the root component is augmented by the Count ADT. A Clock architecture Handler is a method inside a Component or an ADT.

define Adligo's link generation functions. The dictionary has two functions:

- (i) Function C maps a UAN context to a Clock architecture component.
- (ii) Function D maps a UAN match to a set of components, ADT's, methods, or handler names which might exist as implementations of that UAN match in the Clock architecture.

D simply implements a table lookup in the dictionary: given a UAN match, the corresponding Clock architecture pattern is returned. Since these semantics are straightforward, we do not define D formally. C can be defined in terms of D. To describe D, we assume that the symbol $\perp$ ('bottom') is a distinguished element used to represent a null value. (i.e., if S is a set, then $S_{\perp} = S \cup \{\perp\}$.) P denotes the power set. The dictionary sequentially searches (top to bottom) for a matching rule using the D function, which has the following signature:

$$D: \text{Match} \rightarrow P(\text{ComponentOrADT}_{\perp} \times \text{Method}_{\perp})$$

D takes a UAN match as argument and maps it to a set of components, ADT's, methods, or handlers. The function returns a set because the pattern language allows a UAN match to be mapped to multiple potential targets in the Clock architecture (see section 4.3.8).

C has the following signature:

$$C: \text{Context} \rightarrow \text{ContextComponent}_{\perp}$$

where $\text{Context} \subseteq \text{Match}$ and $\text{ContextComponent} \subseteq \text{Component}$. ContextComponent represents the Clock architecture components which may be a translation of the UAN context.

The C function accepts a UAN match (ts) representing the UAN context, or a referenced subtask which causes changing the context (see section 4.3.2), and translates ts to an architecture component e . If ts is not found in the dictionary, the function returns $\perp$. C is defined as:

$$C(ts) = \begin{cases} e, & \text{if } \exists e \in \text{ContextComponent} \bullet D(ts) = \{ (e, \perp) \} \\ \perp, & \text{otherwise} \end{cases}$$

5.3 The Routing Functions

The routing functions in the Clock architecture play an important role in defining the link generation functions which Adligo implements. Since these functions were defined formally in [GRAHAM, 1995], we do not define them here, but we define Adligo's functions in terms of them. There are two routing functions in the Clock architecture style:

- (i) Function R_{Action} searches the scope of the context component to find the first component or ADT that implements the first instance of any method among the multiple targets mentioned in the Clock architecture pattern. We use this routing function to define the functions which generate links for the *user actions* column.

- (ii) Function R_{state} which searches for the first ADT in the context component scope that implements one of the methods mentioned in the Clock architecture pattern. We use this routing function to define the functions which generate links for the *interface state* and *connection to computation* columns.

Figure 5.4 provides an example of the use of R_{action} . In step (1), Adligo uses the dictionary function C to translate the UAN context (“n”) to the Clock architecture component (“nodeView”) using the following rule:

	n	nodeView
--	---	----------

In step (2), Adligo uses the D function of the dictionary to translate the UAN match “~[x, y]” to a set of candidate methods {relMotion, motion} using this rule:

	~[\$(obj1), \$(obj2)]	relMotion motion
--	-------------------------	--------------------

Adligo uses the R_{action} function to find the first component or ADT which has the first instance of these methods. Since the “MousePosition” ADT has the method “motion”, this makes (“MousePosition”, “motion”) the correct handler. R_{action} has the following signature:

$R_{action}: P(\text{Method}) \times \text{ContextComponent} \rightarrow \text{Handler}.$

Figure 5.4. Generating links for user actions. Step (1) translates the UAN context to a component. Step (2), Adligo uses the dictionary function `D` to translate the match `"-[x,y]"` to a set of multiple target methods represented by the set `mSet`. `RAdligo` seeks the first component or ADT which intercepts the first instance of any method in `mSet`.

The first argument is a set of candidate methods resulting from translating a UAN match using the D function. The second argument of $R_{Action(m)}$ is the context component, which is the translation of the UAN context.

Figure 5.5 provides an example of the use of R_{State} . In step (1), Adligo uses the dictionary function C to translate the UAN context “n” to “nodeView” using the rule:

	n	nodeView
--	---	----------

In step (2), Adligo uses the D function of the dictionary to translate the UAN match “count +=1” to a set of candidate methods {incCount, incrementCount} using this rule:

	$\$(var1) += 1$	inc\$(var1) increment\$(var1)
--	-----------------	---------------------------------

Adligo uses the R_{State} function to find the first ADT which implements any method in mSet. The “Counter” ADT implements the method “incrementCount”. This makes (“Count.increment”, “Count”) the correct handler. R_{State} has the following signature:

$$R_{State}: P(\text{Method}) \times \text{ContextComponent} \rightarrow \text{ADT} \times \text{Method}.$$

R_{State} searches the Clock architecture for the correct handler (ADT, method). The first argument is a set of candidate methods resulting from translating a UAN match using the D function. The second argument of R_{State} is the context component, which is the translation of the UAN context.

Figure 5.5. Generating links for interface state or connection-to-computation columns. Step (1) translates the UAN context to a component. In step (2), Adligo uses the dictionary function D to translate the “count + 1” match to a set of candidate methods $mSet$. Adligo uses the R_{state} routing function to find the first ADT that implements any method in $mSet$, starting from the current context of “nodeView”.

In the following sections, we define Adligo's link generation functions in terms of these routing functions.

5.4 Linking *User Actions*

Identifying the context component in the Clock architecture is significant to the link generation process. Therefore, Adligo maintains an internal system variable `contextComponent` which represents the translation of the current UAN context. In the *user actions* column, the link generator keeps track of two important user actions: the context change action denoted by " $\sim$ [newContext]" and subtask referencing (see sections 4.3.2). Both can alter the UAN context, causing Adligo to translate the UAN context to an architecture component (using the dictionary function C) and to assign this translation to the variable `contextComponent`.

For other user actions (which have no impact on the UAN context), the link generator looks up the dictionary for a translation using the D function, and uses the routing function R_{action} to find the correct handler for this user action.

We can describe the signature of the function G_A which generates the links for a sequence of user actions in a given component context as follows:

$$G_A: \langle \text{Match} \rangle \times \text{ContextComponent} \rightarrow P \text{ Link}$$

G_A takes two arguments. The first is a sequence of user action matches, and the second is the context component. The function returns a set of links associating that sequence of user actions with the Clock architecture.

To define this function, we identify those sequences of tokens which represent a subtask name; i.e., we let $\text{Subtask} \subseteq \langle \text{Token} \rangle$, and we assume: $c \in \text{ContextComponent}$, $c' \in \text{Context}$, $a \in \text{Match}$, $as \in \langle \text{Match} \rangle$. Then we define the function G_A through the following set of equations:

$$G_A(\langle \rangle, c) = \emptyset,$$

if no user actions are present, no links are generated.

$$G_A(\sim[c']|as, c) = G_A(as, C(c'))$$

$\sim[c']$ is the change context action. This action is not linked but the remaining actions (as) should be linked with respect to the new context component $C(c')$. The notation $\langle X \mid Xs \rangle$ represents a sequence in which X is the first element and Xs represents the sequence of the remaining elements.

$$G_A(\langle a \mid as \rangle, c) = \begin{cases} G_A(as, C(a)), & \text{if } a \in \text{Subtask} \wedge C(a) \neq \perp \\ G_A(as, c), & \text{if } (a \in \text{Subtask} \wedge C(a) = \perp) \vee D(a) = \emptyset \\ \{(a, R_{\text{Action}}(D(a), c))\} \cup G_A(as, c), & \text{otherwise} \end{cases}$$

Choice no. 1: If a is a subtask reference that has a translation in the dictionary, then the remaining user actions as are linked with respect to the new context component $C(a)$. Choice no. 2: If a is a subtask reference that has no translation, or a is another user action with no mapping rule in the dictionary, then a is ignored and the remaining user actions as are linked with respect to the current context. Choice no. 3: If the previous conditions are not satisfied, then the result of the function $G_{\setminus}$ is the set of links resulting from mapping the actions a and as .

5.5 Linking *Interface State* and *Connection to Computation*

The UAN description in the *interface state* and *connection to computation* columns mainly describes the system's data. Therefore, most of the UAN matches in these columns are mapped to methods inside ADT's. The same link generation rules apply to these columns and we describe the link generation rules in terms of the *interface state* column.

We describe the G_s function which generates links for the interface state column by the following signature:

$$G_s: \langle \text{Match} \rangle \times \text{ContextComponent} \rightarrow P \text{ Link}$$

G_s takes two arguments. The first is a sequence of interface state matches, and the second is the context component. The function returns a set of links associating that sequence of interface state matches with the Clock architecture. To define this function, let us assume $c \in \text{ContextComponent}$, $s \in \text{Match}$, $ss \in \langle \text{Match} \rangle$. G_s is then defined through the following equations:

Figure 5.6. Generating links for the interface feedback column. In step(1), Adligo translates the UAN context “n” to the component “nodeView”. In step(2), Adligo translates the “rubber-band line” using the dictionary function D to the explicit handler (“rubberBand”, “view”). In step (3), Adligo finds no translation for the “n!” match, so it links it, by default, to the “view” method of the context component “nodeView”.

$$G_S(<>, c) = \emptyset,$$

if no interface state matches are present, no links are generated,

$$G_S(<s|ss>, c) = \begin{cases} G_S(ss, c), & \text{if } D(s) = \emptyset \\ \{ (s, R_{state}(D(s), c)) \} \cup G_S(ss, c), & \text{otherwise} \end{cases}$$

Choice no.1: If there is no dictionary rule which matches the interface state s , then ignore it, and generate links for the remaining interface state matches ss . Otherwise, in choice no. 2, the result of the function is the set of links generated for the interface state s and for ss .

5.6 Linking *Interface Feedback*

Lastly, in the *interface feedback* column the link generator in Adligo searches the dictionary for a match. If found, the dictionary translation should be a handler: the component name and its *view* method (figure 5.6, step(2)). However, the Adligo user does not need to explicitly map every feedback description, because Adligo, by default, links it to the *view* method of the context component (figure 5.6, step(3)). We describe the function G_F , which generates the links for the interface state matches by the following signature:

$$G_F: \langle \text{Match} \rangle \times \text{ContextComponent} \rightarrow \text{P Link}.$$

To define this function, we assume $c \in \text{ContextComponent}$, $c' \in \text{Component}$, $m \in \text{Method}$, $f \in \text{Match}$, $fs \in \langle \text{Match} \rangle$. We define G_F through the following equations:

$$G_F(<>, c) = \emptyset$$

if no interface feedback matches are present, no links are generated,

$$G_F(\langle f | fs \rangle, c) =$$

$$\begin{cases} \{ (f, (c, \text{"view"})) \} \cup G_F(fs), & \text{if } D(f) = \emptyset \\ \{ (f, \{ (c', m) \}) \} \cup G_F(fs), & \text{where } \{ (c', m) \} = D(f), \text{ otherwise} \end{cases}$$

Choice no. 1: is the default set of links resulting from mapping the f match to the context component (c) plus the links that map the remaining interface feedback matches fs . Otherwise, in choice no. 2, if f is matched by a dictionary rule, then the function returns a set of links consisting of a link that maps f and the links mapping the remaining interface feedback matches fs .

The process continues line by line until it finishes an entire UAN table. Adligo proceeds to the next table until all the UAN model tables are mapped. At that moment, the link generation process terminates. The final result is a set of links associating the UAN model to the Clock architecture. Adligo writes these links to a text file.

In order to display visually the results, we use the *Vista* tool [BROWN et al., 1998]. Vista needs specially formatted files in order to be able to demonstrate the links between the UAN model and the Clock architecture. It needs some files that represent the UAN and the Clock architecture models. In order to generate these files, the parse trees of both models are passed to the *ClockArch-Vista files generator* and the *UAN-Vista files generator*. The generated links are also formatted properly to be read by Vista. Upon preparing this set of files for Vista, we can graphically navigate the links associating the two models.

5.7 Summary

The chapter was concerned with implementation aspects of the link generation process. It technically explained the general framework of this process. It described one primitive function (D) for the dictionary, and two of the routing rules (R_{Action} and R_{State}) existing in the Clock architecture style. D is a simple table look-up. The routing functions were formally specified [GRAHAM, 1995]. We used these predefined functions to define the functions which Adligo implements to derive links for the various UAN table columns. That description was intermingled with some mathematical notations in order to express the concepts formally.

From the technical discussion presented in this chapter, we notice that Adligo has little knowledge about the UAN and the Clock architecture models. This internal knowledge is hard-wired inside Adligo as built-in rules. The first rule relies on the notion of identifying the UAN context and gets its translation in the Clock architecture. The second rule relies on using the routing mechanisms of the Clock architecture style. Any other rules needed to generate links can be externally written in the dictionary by Adligo users.

Chapter 6

EXPERIMENTS AND ANALYSIS

Adligo is the computer-based tool that has been developed to support this thesis's hypothesis. It accepts a UAN task model and a Clock architecture, and links them together with the assistance of a third input, which is the *dictionary*.

This chapter reports on two case studies involving these applications: a project planner and a video annotator. While these case studies show that *Adligo* is able to derive links with high accuracy and completeness, further experiments would be required in order to conclude that similarly positive results would be obtained for other applications.

This chapter is organized as follows. Section 6.1 discusses the measures which we used to evaluate *Adligo*'s performance. Section 6.2 describes the experiments and the case studies which we performed. In section 6.3, we review our experimental method. Section 6.4 gives the raw results, and section 6.5 concludes this chapter with an analysis.

6.1 Measures

The main goal of our experiments is to get a sense of the difficulty of using Adligo as an automated tool and the accuracy of the links generated by Adligo. Towards this goal, we define the following. Assuming Adligo is run on some task and architecture models,

L_{Adligo} : represents the set of links generated by the *Adligo* tool.

L_{H} : represents the definitive set of links against which we compare the links generated by Adligo. This set of links is created by a human (manually). Section 6.3 explains how we prepared L_{H} for our two major case studies.

We will compare L_{Adligo} against L_{H} . We measure the utility of Adligo based on two criteria: ease of use and accuracy.

1) EASE OF USE

This is measured in terms of the number of rules that designers need to add to the *application-specific* dictionary. The *standard* and *component-based* dictionaries are excluded because they are automatically included in every application and therefore cause no burden to Adligo users. We observe how many customized rules we need to write to get a high rate of correct links (90%) and to get almost all the correct links (99%).

2) ACCURACY

The accuracy of *Adligo*'s results can be measured in terms of two rates (" $||$ " denotes set cardinality):

1) Coverage Rate:

$$\text{Coverage Rate} = ||L_{ci} \cap L_{hi}|| / ||L_{hi}|| \times 100\%$$

This gives the percentage of the correct links generated by *Adlgo*.

2) Error Rate:

$$\text{Error Rate} = ||L_{ci} - L_{hi}|| / ||L_{ci}|| \times 100\%$$

This represents the percentage of links generated by *Adlgo* which are incorrect. A link is considered incorrect if it is not present in the set of links found by the human. If designers are using *Usta* to browse the links that *Adlgo* has generated, this rate tells them the likelihood of a chosen link mapping them to an incorrect part of the opposite model.

6.2 Experiments

Adlgo has been tested using four small to medium sized case studies. The small case studies are the *Counter* and the *Video Player* applications. The medium case studies are the *Critical Path Method (CPM) Planner* [GRAHAM, 1997] and the *Video Annotator* [GRAHAM AND URNES, 1997]. Table 6.4 gives an idea about the size of these case studies in terms of the number of tables and lines in the UAN model, and the number of components, ADT's and methods in the Clock architecture.

	UAN Tables	UAN Lines	Components	ADT's	Methods
CPM Planner	18	122	13	11	92
Video Annotator	19	122	30	20	133

Table 6.1. Some figures reflecting the size of the two case studies used in our experiments.

The *CPM Planner* was described in chapter 3. The *Video Annotator* is another groupware application (shown in figure 6.1) that allows a group of people to review a video that has been previously recorded. End-users can add textual and graphical annotations to frames of interest. In real time, end-users can see the video playing and the annotations of each others. All end-users in the session see the video playing, and see each others' annotations.

This chapter reports the results of the *CPM Planner* and the *Video Annotator* case studies. These applications are sufficiently large to provide interesting results. They were developed and published in support of other researches, before this project was begun.

Figure 6.1. *The Video Annotator: a collaborative tool for annotating videos (reproduced from [BROWN et al., 1998]).*

6.3 Conducting the Experiments

To evaluate *Adligo*'s generated links, we should compare them to the set of manually generated links, which we trust to be complete and correct. We manually derived the links for the *CPM Planner* and the *Video Annotator* case studies without looking at the links that *Adligo* would derive. We then compared our human set of links to those semi-automatically generated by *Adligo*, and in cases of discrepancy, determined whether the manual or generated links were correct. Those links that had been missed in the manual process were added to the manual set. Through this process, we are confident that we have reached a definitive set of links that can be treated as correct.

Before conducting the experiments, we needed to:

- prepare the UAN descriptions for our case studies. The UAN descriptions are manually formatted in a text file because we currently do not have a UAN editor. This file is the task model input to *Adligo*. The grammar of this text format is provided in appendix E.
- prepare the Clock architecture files. These files are easy to get as we use the *ClockWorks* tool, which is capable of writing the entire architecture in a text file. This file is the architectural model input to *Adligo*. The grammar of this text format is provided in appendix F.
- write the *application-specific* dictionary for each case study. This dictionary is constructed by incrementally adding rules to it. This allows us to see the impact of each added rule on *Adligo*'s performance.

#of Rules	#of Links	CORRECT	MISSING	EXTRA
0	0	0	108	0
1	12	12	96	0
2	34	34	74	0
3	44	41	67	3
4	56	53	55	3
5	81	71	37	10
6	110	95	13	13
7	111	96	12	15
8	112	97	11	15
9	114	99	9	15
10	115	100	8	15
11	116	101	7	15
12	117	102	6	15
13	117	104	4	15
14	101	107	1	4
15	108	106	3	0

Table 6.2. The experiment was run sixteen times in the CPM Planner case study. The links were evaluated by the Analyzer tool.

#of Rules	#of Links	CORRECT	MISSING	EXTRA
0	0	0	77	0
1	8	8	69	0
2	16	16	61	0
3	24	24	53	0
4	32	32	45	0
5	41	39	38	2
6	40	40	37	0
7	67	67	10	0
8	68	68	9	0
9	71	71	6	0
10	73	73	4	0
11	74	74	3	0
12	75	75	2	0

Table 6.3. The experiment was run fifteen times in the Video Annotator case study. The links were evaluated by the Analyzer tool.

In our case studies, we take advantage of the application-independent dictionaries - *standard* and *component-based* - by adding them to Adligo. Then we incrementally run our experiment, such that in each run we add a new rule to the *application-specific* dictionary to watch its impact on the performance of the Adligo tool. The experiment stops when we cannot add more rules which improve the quality of the generated links.

Every experiment run involves comparing Adligo's generated links to the human's. The CPM Planner case study has 108 links generated by hand. We ran the experiment fifteen times because we have fifteen application-specific rules. In each run, we needed to compare the generated links with the manually 108 generated links. We developed an *.Analyzer* program that accepts the human links and Adligo's in text files, and identifies any missing, extra, and incorrect links. Figures 6.2 and 6.3 summarize the results got from the Analyzer, where we computed their columns as follows:

$$\text{CORRECT} = || L_G \cap L_H ||$$

$$\text{MISSING} = || L_H - L_G ||$$

$$\text{EXTRA} = || L_G - L_H ||$$

6.4 Results

We tabulate the raw results gathered from the consecutive runs of the *.Analyzer* as shown in Tables 6.2 and 6.3. We use the formulas described in section 6.1 to draw the following graphs:

Figure 6.2. Coverage Rate Analysis for the Adligo tool.

Figure 6.3. Error Rate Analysis for the Adligo tool.

Figure 6.2 represents the coverage rate for the two case studies. This rate was computed as follows:

$$\text{Coverage Rate} = \text{CORRECT} / ||L_{it}|| \times 100\%$$

where $\text{CORRECT} = ||L_{ci} \cap L_{it}||$ from Tables 6.1 and 6.2.

Figure 6.3 represents the error rate for the two case studies. This rate was computed as follows:

$$\text{Error Rate} = \text{EXTRA} / ||L_{ci}|| \times 100\%$$

where $\text{EXTRA} = ||L_{ci} - L_{it}||$ from Tables 6.1 and 6.2.

6.5 Analysis

Using the chart shown in figure 6.2, we wish to measure the difficulty (i.e., in terms of number of rules the user should add) of getting most of the correct links generated by *Adligo*. We observe how many customized rules we need to write to get a high rate of link coverage (90%) and to get almost all the correct links (99%). We summarize the result in Table 6.3.

	Link Coverage (90%)	Link Coverage ($\cong$ 99%)
CPM Planner	8 rules	14 rules
Video Annotator	8 rules	13 rules

Table 6.3. *The Difficulty of getting 90% and 99% of Link Coverage by Adligo.*

This table leads to an interesting observation. We could get about 90% of the links correct by adding the first eight rules in both case studies. If we refer to these rules, we will notice that they are *context-related* rules. These rules mainly translate the context name used in a UAN table to a Clock component. This set of rules represents the first shaded region in Tables 6.2 and 6.3 (to examine these rules, see appendices B and C). We expect that users will be easily able to identify this set of rules (appendices B and C contain the application-specific dictionaries of both case studies).

To generate most (shown as 99%) of the available links, we needed to add about extra six rules to the application-specific dictionary. We expect that some of these rules might not be so hard for the user to come up with (the middle region in tables 6.2 and 6.3), while we admit that the others are subtle and challenging to write (the bottom region). Adding such rules to reach the boundary of 99% of correct links is an effort that the Adligo user should decide whether to make.

The chart in figure 6.3 gives a sense of how much Adligo's user can trust its generated links. I.e., the figure shows percentage error of a chosen link (browsed in *Vista* for example) mapping the viewer to the wrong part in the opposite model. The graph shows that as we add rules to Adligo, we might encounter a low error rate (0%~12%). These errors can be eliminated (as shown in figure 6.3) by adding more rules. Again, adding such subtle rules might not be straightforward for the Adligo user to come up with.

6.6 Summary

This chapter was mainly concerned with evaluating Adligo's performance. We described the methods we used to measure that performance and the nature of experiments we conducted. We also provided the raw results collected from these experiments, and a graphical analysis of them.

From the raw results and their analysis, we notice that the *context-related* rules (the top region in Tables 6.2 and 6.3) have a considerable effect on Adligo's performance. The experiments show that by adding these rules alone we could obtain approximately 90% of the available correct links, with error rates of between 0% and 12%.

The results gathered from these experiments make us argue that we can tweak Adligo as much as we like to get an extremely high quality of results. In both of case studies, we were able to obtain 100% of the correct links with an error rate of 0%. Some of the rules required were subtle, however, requiring an expert level of Adligo usage.

Users must trade off the burden of adding such extra rules versus the desire for getting extremely accurate results. Such a decision is left to the users of the tool.

Finally, we re-state that further experiments are required to determine whether these results generalize to additional applications of Adligo

Chapter 7

CONCLUSION

In this thesis, we have argued that task and architecture models can be semi-automatically linked. To support this hypothesis, we have developed a computer-based tool, *Adligo*, which generates links between the UAN as a task model and the Clock architecture as an architecture model.

Human intervention is still needed in order to enable *Adligo* to generate sufficiently correct links between the two models. That human assistance was given through the new artifact which we created, called the *dictionary*. The dictionary has a capability beyond the traditional translation process because it has translation *rules*. *Adligo* users write these rules in a simple, *pattern language* specially designed to assist *Adligo* in finding a UAN description and linking it to its counterpart handler in the Clock architecture.

We Still Need More Experiments and Case Studies

We conducted a few experiments in order to get a sense of *Adligo*'s performance. Our results show that in two case studies, we were able to generate 90% of possible links with error rate of 0% to 12% with only 8 rules in the dictionary. However, we believe that further experiments are required to determine whether these results generalize to all applications of *Adligo*. (see chapter 6).

Applicability to Other Types of Models

Although we used the UAN notation to represent task models and the Clock architecture to represent architectural models, we could use other styles of models to demonstrate the possibility of achieving this thesis' hypothesis. For instance, we expect that if we adopted the ConcurTaskTrees model (see section 2.1.2), it would be easier to handle than the UAN due to its tighter formality. Chapter 2 highlighted some of the common characteristics between some models. However, we cannot generalize the applicability of our methodology to other models until we try them out.

Adligo Is Helpful

We believe that this semi-automatic approach is helpful, especially when our case studies fall in the large size application domain. If we intend to manually generate the links for such case studies, we might need to derive thousands of links in order to map one model to the other. This is a daunting job without computer assistance.

Are Designers Going to Communicate Better?

We intend by this effort to enhance the communication between the different groups of designers involved in developing user interfaces. We gain a sense of this process when we graphically browse the links using the Vista tool (see chapter 3: Design Artifacts Browsed in Vista). We anticipate that this will lead to communication improvement between user interface designers and software engineers, but we need experiments to be able to assert this claim (see section 7.2: *Future Work*).

At What Time in the Development Process Can We Use Adligo?

It is noteworthy that the linkage process between the models can be carried out at any stage in the development cycle; none of the design artifacts has even to be complete. This is expected to support coevolutionary software development.

Reducing Design Inconsistencies Using Adligo

As we were experimenting with some case studies described in chapter 6, we noticed that deriving these links might unveil flaws in the design artifacts. This process may discover that some tasks in the task model have not been implemented, or that some architectural components are not described in the corresponding task model. In this way, one design model would not be left behind the others, and undesirable inconsistencies can be discovered at any stage during development as the models evolve.

Identifying the Hotspots in the Design Artifacts

As we graphically browse the generated links in Vista, the intensity of the links might lead us visually to the architectural components that are crucial because they implement most of the end-users' tasks. That link intensity might also reveal UAN tasks that are difficult to implement.

Adligo Can Be Tweaked

Our experiments described in chapter 6 have shown that Adligo can be tuned as much as we wish to get the desired degree of accuracy. That is possible due to the presence of the dictionary rules, which are written in the *pattern language*. Users can tweak Adligo by even writing rules that explicitly specify links between the UAN and the Clock architecture model.

Abstraction of Implementation Details

Since we were ultimately concerned with software architecture, our approach in this research was independent of any programming language details. We have been dealing with architecture handlers, i.e., interface specifications (methods inside components), regardless of which language is used to implement these interfaces. Dealing with the architectural model keeps us at a high level in the design that is independent of any implementation details. For example, the architectures of the applications exposed in this thesis were implemented using a functional language similar to Haskell [HUDAK AND WADLER, 1991] called Clock [GRAHAM, 1995]. Recently, this language has been replaced by Java in the TCD tool kit [ANDERSON, 1999] which uses the Clock architecture style. Adopting a particular architecture style, however, is still an implementation decision.

7.1 Future Work

Inherently, the user interface design artifacts incrementally evolve as a response to changes in the system [BROWN et al., 1998]. We are interested in investigating design artifacts as they change; some new links may be required, existing links may become invalid. We wish to observe the impact of the evolutionary design on Adligo's performance.

Adligo might incrementally improve its performance in response to evolutionary design by taking advantage of information obtained from one stage to enhance the quality of the links in the other.

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APPENDIX A

THE STANDARD DICTIONARY

This standard dictionary is generic and can be used by any Adlgo application.

Rule #	DICTIONARY: Standard		
	RULE SCOPE	UAN PATTERN	CLOCK ARCHITECTURE PATTERN
1		Mv^	mouseButton
2		Mv	mouseButton
3		M^	mouseButton
4		~[\$(obj)]	enter
5		[\$(obj)]~	leave
6		~[\$(obj1), \$(obj2)]	motion relMotion
7		~\$(obj1), \$(obj2))	motion relMotion
8		K'\$(obj)'	key
9		K\$(obj))	key
10		K_UP	arrowkey
11		K_DN	arrowkey
12		K_RT	arrowkey
13		K_LF	arrowkey
14		K_TAB	editkey
15		K_BS	editkey
16		K_DEL	editkey
17		K_ESC	editkey
18		K_RET	editkey
19		K_F\$(obj)	functionKey
20		\$(obj)++	increment\$(obj) inc\$(obj) increment
21		\$(obj)+=1	increment\$(obj) inc\$(obj) increment
22		lock	lock
23		unlock	lock
24		unlocked	locked
25		have lock	locked
26		currentPos	mousePosition
27		(x,y)	nodePosition userPosition
28		\$(anyVar) :=	set\$(anyVar)
29		\$(obj1),\$(obj2) :=	setUserPosition

APPENDIX B

THE CPM PLANNER DICTIONARY

This is the application-specific dictionary used in the CPM Planner case study. We could obtain 90% of the possible links by adding the first 8 rules.

Rule #	DICTIONARY: The CPM Planner		
	RULE SCOPE	UAN PATTERN	CLOCK ARCHITECTURE PATTERN
1	Create a new node	select mode	Network
2		mode	button
3		n1	nodeView->connectNode
4		n2	nodeView->connectNode
5		n3	nodeView->connectNode
6	Reposition a node	n	nodeView->browseNode
7		nodeCounter+=1	incrementCount
8		nodeCounter	count
9		nodePos(n) :=	setNodePosition
10		currentMode:=	setMode
11		mode	Mode
12		connect \$(obj1) to \$(obj2)	setConnectionTarget
13		lines	edge.View
14		rubber-band	rubberBand.view
15		solid line from n1 to n3	edge.lineFrom

APPENDIX C

THE VIDEO ANNOTATOR DICTIONARY

This is the application-specific dictionary used in the Video Annotator case study. We could obtain 90% of the possible links by adding the first 8 rules.

DICTIONARY: The Video Annotator			
Rule #	RULE SCOPE	UAN PATTERN	CLOCK ARCHITECTURE PATTERN
1		stop_button	button->highlightedButton ->buttons->videoButtons
2		fwd_button	button->highlightedButton ->buttons->videoButtons
3		rev_button	button->highlightedButton ->buttons->videoButtons
4		ff_button	button->highlightedButton ->buttons->videoButtons
5		annotation_mark	indicator
6		display frame	video
7		drawingBoard	whiteBoard
8		currentFrame:=	indicator.setCount
9		start \$(verb)ing frame counter	\$(verb)Count
10		currentText:=	addText
11		currentText+=	addText
12		add text	addText
13		frame(annotation_mark)	position.count

APPENDIX D

THE PATTERN LANGUAGE GRAMMAR

This grammar describes the full syntax of the pattern language used to write dictionary rules.

$\text{Pattern} \rightarrow \text{UANPattern} \mid \text{ClockPattern}$

$\text{UANPattern} \rightarrow \text{CharsOrVariable} \text{CharsOrVariableList}$

$\text{CharsOrVariableList} \rightarrow \text{CharsOrVariable} \text{CharsOrVariableList}$

$\text{CharsOrVariableList} \rightarrow \epsilon$

$\text{CharsOrVariable} \rightarrow \text{Chars} \mid \text{Variable}$

$\text{Variable} \rightarrow \(Id)

$\text{Chars} \rightarrow \text{Char} \text{CharList}$

$\text{Char} \rightarrow \text{Letter} \mid \text{Digit} \mid \text{Symbol}$

$\text{CharList} \rightarrow \text{Char} \text{CharList}$

$\text{CharList} \rightarrow \epsilon$

$\text{ClockPattern} \rightarrow \text{Handler Alternatives}$

$\text{Alternatives} \rightarrow ' \mid ' \text{ClockPattern}$

Alternatives $\rightarrow \epsilon$

Handler $\rightarrow$ CompOrAdt RestOfHandler

CompOrAdt $\rightarrow \epsilon$

CompOrAdt $\rightarrow$ CharsAndVariables

RestOfHandler $\rightarrow$ '.' Method

RestOfHandler $\rightarrow$ '→' ClockPattern

RestOfHandler $\rightarrow \epsilon$

Method $\rightarrow$ CharsAndVariables

Id $\rightarrow$ Letter LetterOrDigitList

LetterOrDigitList $\rightarrow$ LetterOrDigit LetterOrDigitList

LetterOrDigitList $\rightarrow \epsilon$

LetterOrDigit $\rightarrow$ Letter | Digit

Letter $\rightarrow$ a | b | ... | z | A | B | ... | Z | _

Digit $\rightarrow$ 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Symbol $\rightarrow$! | @ | # | \$ | % | ^ | & | * | (|) | = | + | - |
~ | . | , | ? | ' | ` | \ | < | > | " | ; | : | / |
' | ' | [|] | { | } | , | ' |

APPENDIX E

THE UAN NOTATION GRAMMAR

This grammar describes the syntax we used to write the UAN notation in a text file to be input to the Adligo tool.

$$\text{UAN} \rightarrow \langle \text{name Title} \rangle \text{UANTableList}$$
$$\text{UANTableList} \rightarrow \text{UANTable UANTableList}$$
$$\text{UANTableList} \rightarrow \epsilon$$
$$\text{UANTable} \rightarrow \langle \text{begin Title} \rangle \text{TableContent} \quad \langle \text{end table} \rangle$$
$$\text{Title} \rightarrow \text{Char CharList}$$
$$\text{TableContent} \rightarrow \langle \text{expand Title} \rangle$$
$$| \langle \text{line} \rangle$$
$$| \text{SpecLine}$$
$$\text{SpecLine} \rightarrow \text{UANSpec} \ ; \ \text{UANSpec} \ ; \ \text{UANSpec} \ ; \ \text{UANSpec} \ ;$$
$$\text{UANSpec} \rightarrow \text{Char CharList}$$
$$\text{UANSpec} \rightarrow \epsilon$$
$$\text{CharList} \rightarrow \text{Char CharList}$$
$$\text{CharList} \rightarrow \epsilon$$

Char → Letter | Digit | Symbol

Letter → a | b | ... | z | A | B | ... | Z | _

Digit → 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9

Symbol → ! | @ | # | \$ | % | ^ | & | * | (|) | = | + | - |
~ | . | , | ? | ' | ` | \ | < | > | " | : | / | ' | '
| [|] | { | } | ' | '

APPENDIX F

THE CLOCK ARCHITECTURE FILE GRAMMAR

This is the grammar we used to parse the Clock architecture files generated by ClockWorks.

`ClockArchitecture` $\rightarrow$ `Constraint` `ConstraintList`

`ConstraintList` $\rightarrow$ `Constraint` `ConstraintList`

`ConstraintList` $\rightarrow$ ϵ

`Constraint` $\rightarrow$ `update` `MethodName` `StrLit` .

`Constraint` $\rightarrow$ `request` `MethodName` `StrLit` `StrLit` `StrLit` .

`Constraint` $\rightarrow$ `rhClass` `ADTName` .

`Constraint` $\rightarrow$ `rhClassTakesUpdate` `ADTName` `MethodName` .

`Constraint` $\rightarrow$ `rhClassTakesRequest` `ADTName` `MethodName` .

`Constraint` $\rightarrow$ `rhClassTakesHiddenUpdate` `ADTName` `MethodName` .

`Constraint` $\rightarrow$ `ehClassMakesRequest` `EhClassName` `MethodName` .

`Constraint` $\rightarrow$ `ehClassTakesUpdate` `EhClassName` `MethodName` .

`Constraint` $\rightarrow$ `ehClassTakesRequest` `EhClassName` `MethodName` .

`Constraint` $\rightarrow$ `ehClassMakesUpdate` `EhClassName` `MethodName` .

Constraint $\rightarrow$ ehClass EhClassName EhNameList .

Constraint $\rightarrow$ ehClassMakesRequest EhClassName MethodName .

Constraint $\rightarrow$ eventHandler InternalEhName EhClassName .

Constraint $\rightarrow$ requestHandler InternalRhName RhClassName .

Constraint $\rightarrow$ rhBelongsToEh InternalRhName InternalEhName .

Constraint $\rightarrow$ ehChildOfEh InternalRhNameList EhName .

Constraint $\rightarrow$ root InternalEhName

InternalRhNameList $\rightarrow$ InternalRhName InternalRhNameList

InternalRhNameList $\rightarrow \epsilon$

EhNameList $\rightarrow$ EhName EhNameList

EhNameList $\rightarrow \epsilon$

MethodName $\rightarrow$ Id

ADTName $\rightarrow$ Id

EhName $\rightarrow$ Id

EhClassName $\rightarrow$ Id

$\text{InternalEhName} \rightarrow \text{Id}$

$\text{InternalRhName} \rightarrow \text{Id}$

$\text{StrLit} \rightarrow \text{" Characters "}$

$\text{Characters} \rightarrow \text{LetterOrDigit Characters}$

$\text{Characters} \rightarrow \epsilon$

$\text{Id} \rightarrow \text{Letter LetterOrDigit}$

$\text{LetterOrDigit} \rightarrow \text{Letter} \mid \text{Digit}$

$\text{Letter} \rightarrow \text{a} \mid \text{b} \mid \dots \mid \text{z} \mid \text{A} \mid \text{B} \mid \dots \mid \text{Z} \mid _$

$\text{Digit} \rightarrow 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9$