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Software Architectures and Integration Testing

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1 Introduction

In recent years the focus of software engineering is continuously moving towards systems of larger dimensions and complexity. Software production is becoming more and more involved with distributed applications running on heterogeneous networks, while emerging technologies such as commercial off-the-shelf (COTS) products are becoming a market reality [20].

As a result, applications are increasingly being designed as sets of autonomous, decoupled components, promoting faster and cheaper system development based on COTS integration, and facilitating architectural changes required to cope with the dynamics of the underlying environment.

In this context Software Architecture (SA) can play a significant role. SAs have in the last years been considered, both by academia and software industries, as a means to improve the dependability of large complex software products and own concepts, formalisms, methods and tools have been introduced [13, 21, 12, 3, 6].

The software architecture of a large complex system supplies information about how the software is structured in parts and how those parts interact. Besides the static characteristics of a system, Software Architectures require the ability to describe dynamics at a *relevant* level of abstraction as well as the ability of expressing extra-functional requirements. As the complexity of software systems increases, the importance of Software Architectures becomes evident for the analysis, design and construction of the overall system structure. They represent the most promising approach to tackle the problem of scaling up in software engineering.

Testing is one of the most expensive activities in the development of complex software systems.

Traditionally, the testing of large software systems proceeds in subsequent steps following the well-known *V* model: unit, integration and system test, which correspond in bottom-up order to the code, design and specification stages of the development part of the life-cycle, (proceeding conversely in top-down fashion).

Nowadays, the emergence of new paradigms, centered on component-based assembly of systems, let suppose a software process in which unit testing plays a minor role, and testers have to focus more and more on how components work when plugged together.

However, while new models and methods have been proposed with respect to requirements analysis and design (notably UML [19]) and analysis of the consistency and

correctness of the SA as advocated in some works [6], how to approach the testing of these kinds of systems remains a neglected aspect and the following problems have to be solved:

- it is difficult to formalise and automate the integration testing stage, because the selection of test cases for the subcomponents and the order in which they are tested is entirely dependent on the adopted system functionality decomposition, which is hardly formalised. Integration test is thus normally devised ad hoc for each new system.
- The conventional approach to integration testing stresses structure over behavior: in fact, it is often explicitly stated that the goal of integration test is to check the compatibility between component interfaces. However, software components naturally embody assumptions about both the structure and the behavior of the contexts in which they are integrated. Besides conflicts between the information of static type present in the interfaces, when components are put to work together, conflicts can also arise in their dynamic interaction (*mismatch* [10, 11]). Conventional integration testing, by stressing the structural aspects of the decomposition, is not well suited to uncovering the latter.
- When existing components are re-used in the integration of the system, it is difficult to exploit previous test results.

Our research activity is directed to address these problems by using the software architecture of the system as the primary base. We intend to investigate how testing (in particular, integration testing) can be devised and controlled based on the software architecture. Indeed, since software architectures can provide a formal and explicit description of both static and dynamic properties of a system, as composed by components and connectors, the advantages can be manifold:

- the same design of an architecture could be used to steer the testing of the system during integration test. In general, the components and the connectors for a specific architecture are selected from a restricted collection (constrained by the adopted architectural style) and therefore the complexity of the testing task would be reduced because restricted to the style;
- the use of architectures should facilitate re-use of components. Consequently, regression test and re-use of test results of a component previously tested within other architectures should be facilitated as well;
- architectures typically specify information also about extra-functional properties of components and connectors. Therefore it should be possible to exploit the architecture specification to test for extra-functional requirements.

We will rely on descriptions of software architectures based on the Chemical Abstract Machine (Cham) formalism as introduced in [5, 14].

2 Cham Descriptions of Software Architectures

The peculiarity of Software Architecture descriptions in term of levels of abstraction and information content does not permit to straightforwardly export concepts, methods

and languages widely used in the specification of software systems to the description of Software Architectures [1, 14, 2].

Our attempt in using the Cham formalism for software architectural specifications is to propose an appropriate level of description by discriminating among details that have to be included in the description and those that have to be excluded. Moreover we are interested in expressing extra-functional constraints on the architecture to be refined. By extra-functional requirements we mean all those requirements that are meaningful for the customer but have no impact on the functional behaviour of the system. For example, requirements on the topology of the system architecture due to hardware or physical constraints or fault-tolerance requirements which may result in the need of replicating resources. From our perspective, the key issue here is in the ability of expressing these properties in the same formalism used for the specification of the functional/behavioural ones [21]. To this respect, we have experimented the use of the Cham formalism to describe the structural distribution of the components, i.e. the topological schema which has a *static* nature, and the issue of describing the (possibly different) interaction modalities among the various components, i.e. the *dynamic* structure [15, 9, 10].

In the following we briefly summarize the most relevant concepts the Cham model is based on.

A Chemical Abstract Machine specification contains *Molecules* m_1, m_2, \dots the basic elements of a Cham, and *solutions* S_0, S_1, \dots multisets of molecules interpreted as defining the *states* of a Cham; *transformation rules* T_1, T_2, \dots define a *transformation relation* $S_i \longrightarrow S_j$ dictating the way solutions can evolve (i.e., states can change) in the Cham. Following the chemical metaphor, the term *reaction rule* is used interchangeably with the term *transformation rule*.

The transformation rules can be of two kinds: (four) general *laws* that are valid for all Chams and specific *rules* that depend on the particular Cham being specified.

The initial solution corresponds to the initial, static configuration of the system. We require the initial solution to contain molecules modeling the initial state of each component. Transformation rules applied to the initial solution define how the system dynamically evolves from its initial configuration.

A Cham description of a software architecture consists of a syntactic description of the static components of the architecture (the *molecule*) and of a set of reaction rules, beside the general ones, which describe how the system dynamically evolves through reaction steps.

The Cham formalism allows for two, quite different analysis techniques which permit to analyze and verify various properties of the system under specification including the usual *safety* and *liveness* properties. On the one hand, we can exploit the algebraic and equational nature of Cham. On the other hand, one can take advantage of this operational flavor to derive an LTS out of a Cham description whose node and arc labels represent respectively states and transitions relevant in the context of the SA dynamics.

3 The approach

In the following we describe the research directions we are currently working on to improve the software testing process. Our goal is to use the SA specification as a reference model to test the implemented system.

Although our approach builds on the Cham description of a SA it is worthwhile stressing that it is not committed to it. Our choice of the Cham formalism is dictated by our background and by its use in previous case studies. We are perfectly aware that other choices could be made and want to make clear that the use of a specific formalism is not central to our approach.

We identify interesting test classes for SA-based testing as sequences of interactions between SA components. More precisely, starting from an architectural description, carrying on both static and dynamic information, we first derive a *Labelled Transition System* (LTS), that graphically describes the SA dynamics. The problem is that the LTS provides a global, monolithic description of the set of all possible behaviors of the system. It is a tremendous amount of information flattened into a graph. It is quite hard for the software architect to single out from this global model relevant observations of system behavior that would be useful during validation.

We provide the software architect with a key to decipher the LTS dynamic model: the key is to use *abstract views* of the LTS, called ALTSs, on which he/she can easily visualize relevant behavioral patterns and identify those ones that are more meaningful for validation purposes. Test classes in our approach correspond to ALTS paths. However, once test class selection has been made, it is necessary to return to the LTS and retrieve the information that was hidden in the abstraction step, in order to identify LTS paths that are appropriate refinements of the selected ALTS paths.

Each selected LTS paths in our approach represents a test class for integration testing.

Lot of work has been devoted to testing concurrent and real-time systems, both specification driven and implementation based [7, 8, 16, 17, 18, 4] but all focus on unit testing.

Thus although the technical tools some of these approaches use are obviously the same of ours (e.g., LTS, abstractions, event sequences), their use in our context is different. This goal difference emerges from the very beginning of our approach: we work on an architectural description that drives our selection of the abstraction, i.e., the testing criterion, and of the paths, i.e., the actual test classes.

We definitely believe that the success of the approach described heavily depends on the availability of simple and appealing supporting tools. Our long term aim is to achieve a usable set of tools that would provide the necessary support to architecture-based testing. Our effort goes in two directions, on one side we are investing on automating our approach and we would also like to take advantage of other existing environments and possibly integrate with them, on the other we are involved in more experimentation. So far, we have developed the LTS generator starting from the Cham description, which also allows for keeping track of the state and arc labels. Work is ongoing to generalize it to ALTS generation and to implement a graphical front-end for Cham descriptions. Experimenting our approach is not an easy task, it requires the existence of a correct architectural description and a running implementation. This is obviously not often the case. The results we got so far for a real world case study are quite satisfactory and there are other real world case studies we are working on at the moment. We are confident these will provide other interesting insights to validate our approach.

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Topics

- Integration Testing +
- Software Architecture =

Architecture-based Testing

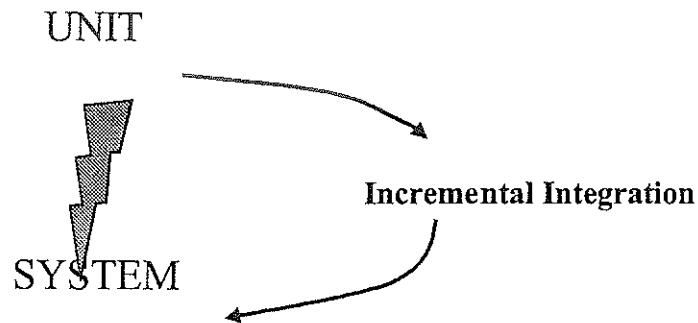
- Unified Modeling Language
- Software Architecture Analysis
- Software Architecture Validation
- Traceability

1

Integration Testing

A two tiers problem:

- *how do we select an adequate and feasible set of tests?*
- *how do we decompose the test object into "manageable" pieces?*



2

Software Architecture

- Describes (in a formal language) how a system is structured into components and how these components interact

SA = Structure + Behavior
(states) & (dynamics)

3

Architecture-based Integration Testing

- Integration Testing is aimed at exposing problems in the interfaces and interactions between the system components
- SA descriptions carry on exactly the information needed to derive an integration testing strategy

4

Envisaged benefits

- Right level of abstraction (not too much, not too little)
- Explicit representations of early design decisions (hardest to change)
- Provides a context for component-based testing
- Rigorous conceptual basis for the testing of non-functional properties
- Confinement within a specific architectural style (patterns for testing)

5

Software Architectures and Integration Testing

Overview

- Step1: Requirements Study and Analysis
- Step2: Software Architecture Description
- Step3: SA Dynamics: LTS and ALTS
- Step4: Test Plan (Event sequences)
- Step5: Architectural Sequence Diagram
- Step6: UML Sequence Diagram
(Implementation perspective)
- Step7: Refined Test Case

6

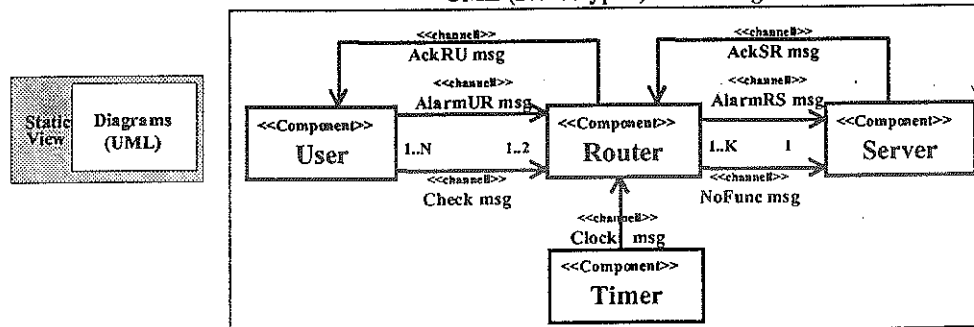
TRMCS Case Study

- TRMCS Components and Connectors:
 - User: sends an Alarm or a Check message to the Router
 - Router: receives User Alarm and Check, receives a Clock message, sends Alarm and Nofunction message to the Server
 - Server: receives Router Alarm and Nofunction message
 - Timer: sends a Clock message to the Router

- MultiUser, Concurrent, Real-Time

Software Architecture: Static Description

UML (Stereotyped) Class Diagram



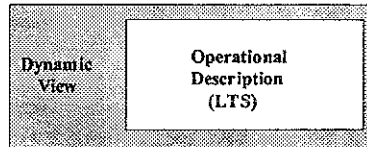
- Formal Description
- Graphical, Readable Notation
- UML and Software Architecture

ADL Description

Molecule syntax:
Molecule: Process|Operation| M.M
Process: User, Router, Server, Timer
Channel: check, alarmUR, alarmRS, ackRU, ackSR, nofunc, clock
Operation: i(Channel), o(Channel), ...

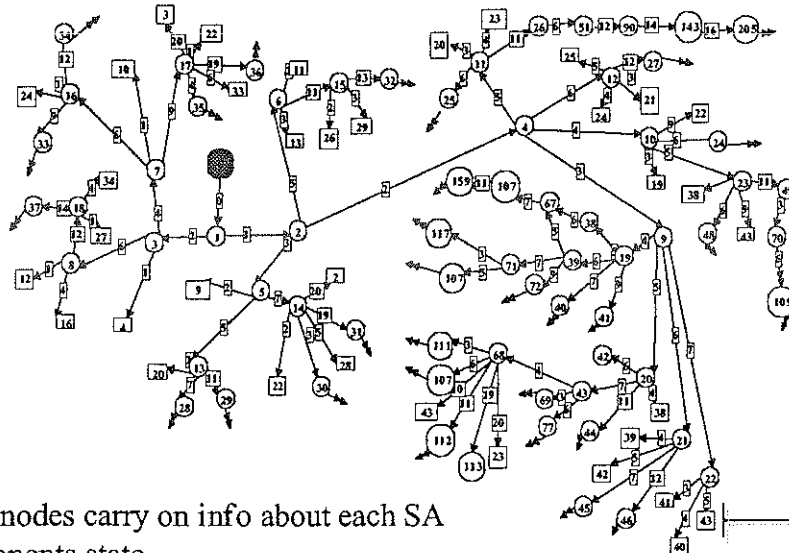
InitialState (S0):
 Multiset of Molecules: m1, m2, ..., mn

Rules:
 m1, m2, ..., mk → m1', m2', ..., ml'

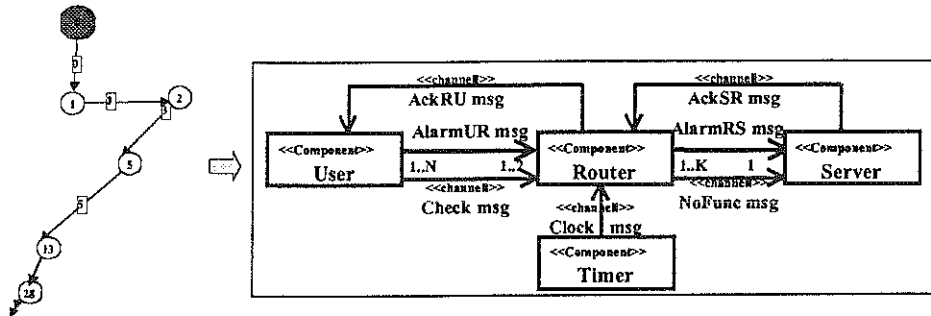


- Architectural Description Language (ADL) & Labelled Transition System (LTS)
- Chemical Abstract Machine (CHAM)
- Dynamics in terms of Component interactions

LTS Dynamic Description

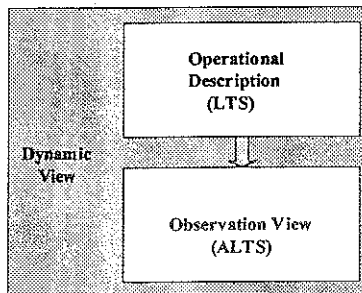


Note: nodes carry on info about each SA components state



- LTS paths and Component Interaction via Connectors
- High number of paths ⇒ High System Complexity

The Tool: Abstractions



- Architectural Views
- Obs_Functions
- Abstract Labelled Transition System (ALTS)
- Minimization and Reduction

Software Architectures and Integration Testing

$D = \{SendAlarm1, SendAlarm2, ReceiveAck1, ReceiveAck2\}$

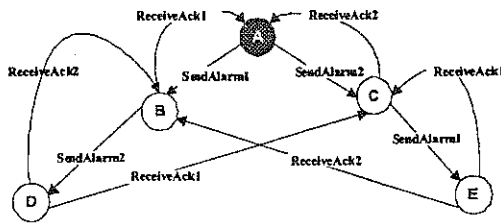
$obs(T_{11}) = SendAlarm1$: User1 issues an Alarm msg
 $obs(T_{17}) = ReceiveAck1$: User1 receives an Ack
 $obs(T_{12}) = SendAlarm2$: User2 issues an Alarm msg
 $obs(T_{18}) = ReceiveAck2$: User2 receives an Ack

For any other T_i , $obs(T_i) = \tau$

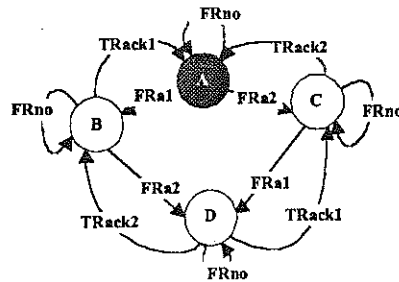
$D = \{FRa1, FRa2, TRa1, TRa2, FRno\}$

$obs(T_{13}) = FRa1$: Alarm1 msg From Router
 $obs(T_{14}) = FRa2$: Alarm2 msg From Router
 $obs(T_{15}) = TRa1$: Ack1 msg To Router
 $obs(T_{16}) = TRa2$: Ack2 msg To Router
 $obs(T_{21}) = FRno$: NoFunction msg From Router

For any other T_i , $obs(T_i) = \tau$



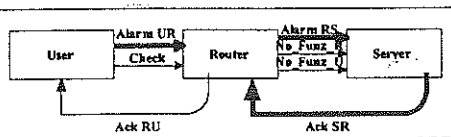
Flow view (Alarm Flow)



ComponentBased View (Server Component)

Software Architectures and Integration Testing

From SA to ALTS



Molecule syntax:

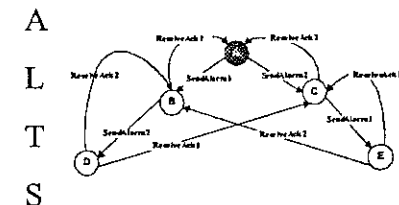
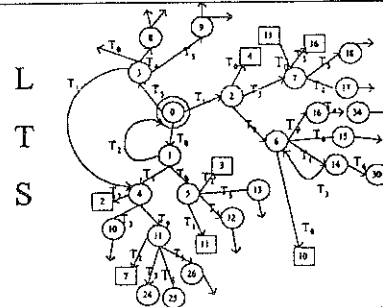
Molecule: Process | Operation | M.M
Process: User, Router, Server, Timer
Channel: check, alarmUR, alarmRS, ackRU, ackSR, nofunc, clock
Operation: i(Channel), o(Channel), ...

InitialState (S0):

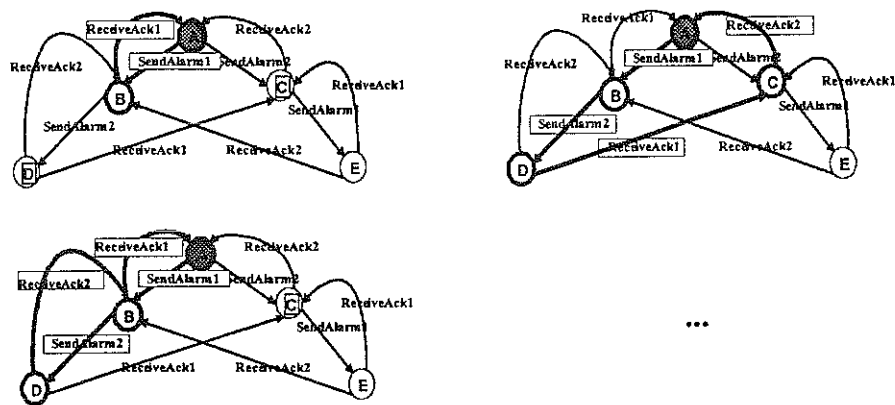
Multiset of Molecules: $m1, m2, \dots, mn$

Rules:

$m1, m2, \dots, mk \rightarrow m1', m2', \dots, m'$



Software Architectures and Integration Testing

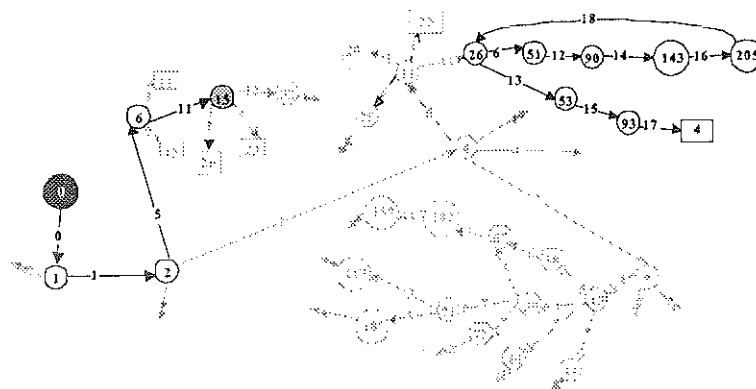


- ALTS Path Coverage
- Architectural Test Plan

15

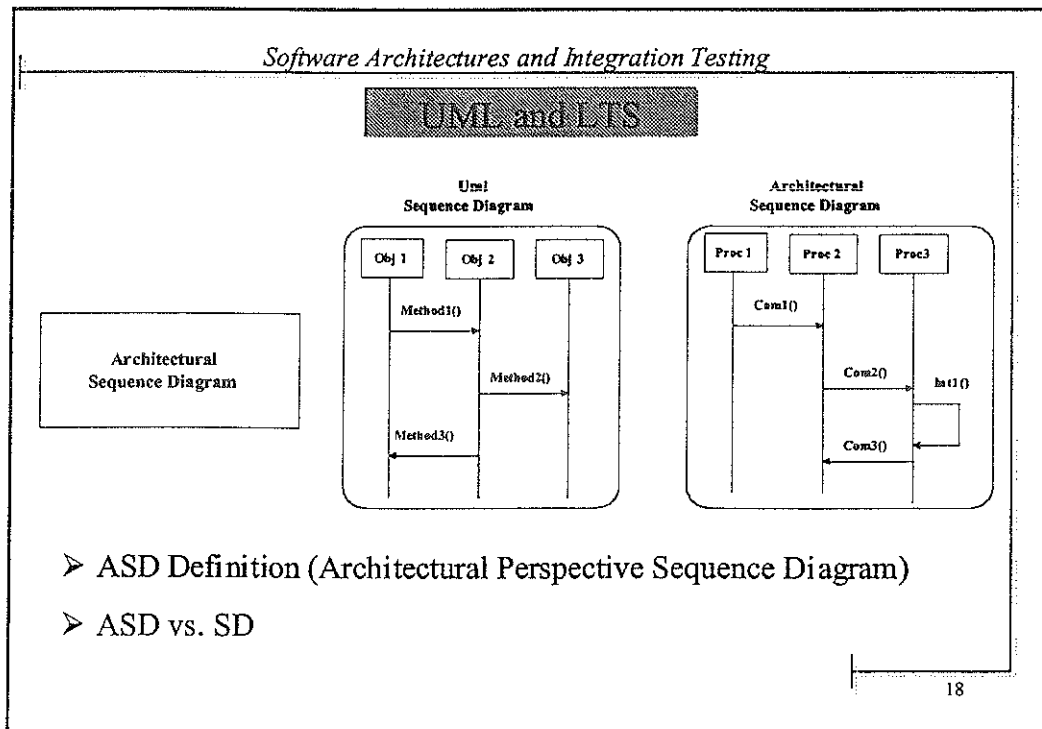
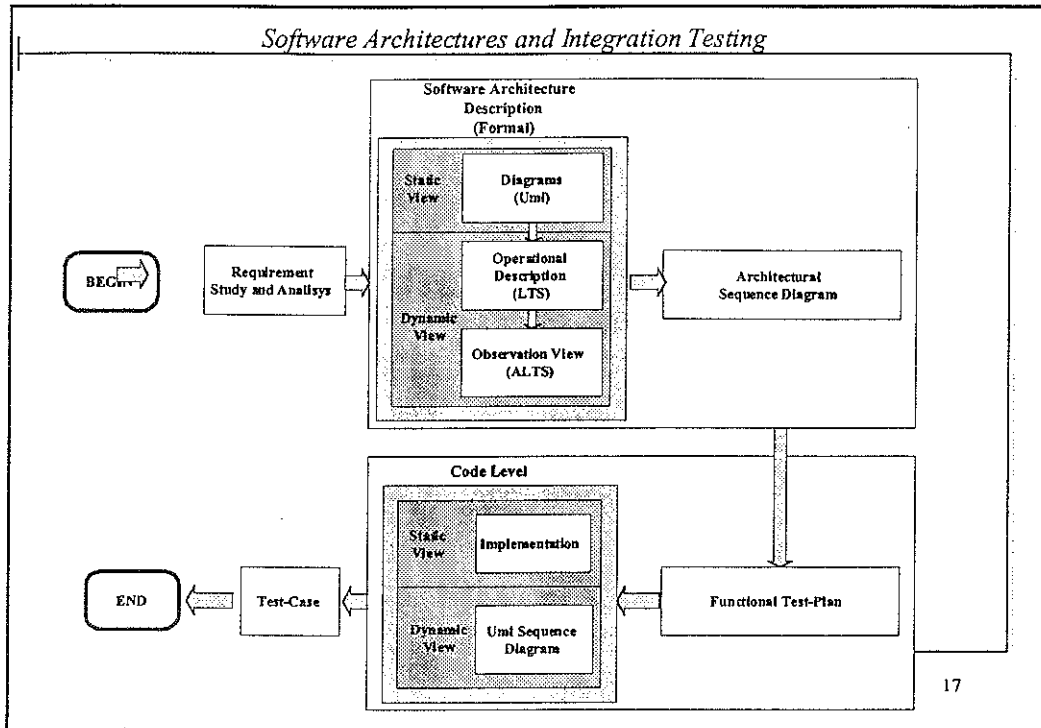
Software Architectures and Integration Testing

From ALTS to LTS



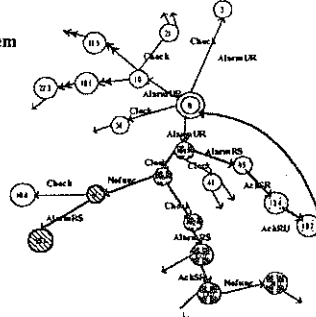
- LTS selective coverage (SendAlarm1, SendAlarm2, ReceiveAlarm2, ReceiveAlarm1)

16

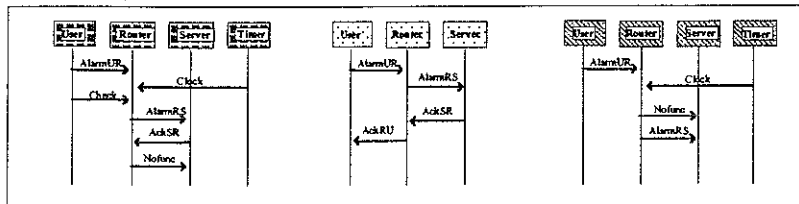


Software Architectures and Integration Testing

Abstract Labelled Transition System (ALTS)



Architectural Sequence Diagram (ASD)



➤ from ALTS to ASD

Software Architectures and Integration Testing

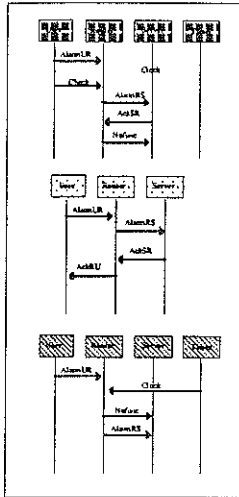
Traceability:
From LTS path to Code

- Re-architecting context:
 - SA and Code are independent

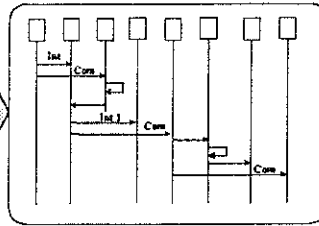
- Forward development process
 - COTS, component based

Re-architecting context

Architectural Sequence Diagram



Uml Sequence Diagram (Code Level)

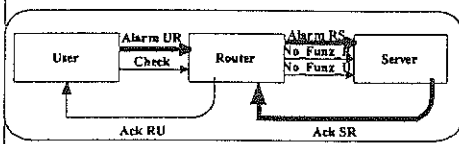


Trace

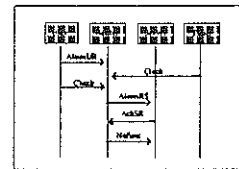
- Deterministic Test
- Non Deterministic Test
- Conformance Test

Forward development

Software Architecture



Architectural Sequence Diagram

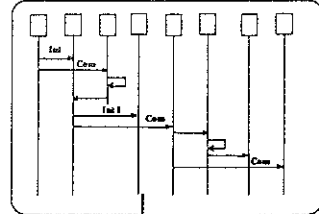


Requirements & Use-Case

Use Case UC1.1	
Summary	
Type	
Actors	
Priority	
Frequency	
Starting Event	
Pre-Conditions	Exception
Description	
Post-Conditions	Exception
Uses	
Extension	

Methodology

Design consistency



Uml Sequence Diagram

The Present

- LTS can be automatically derived from a Cham Specification
- ALTS can be semi-automatically generated
- ALTS to LTS step is not automatically managed
- Deterministic-Testing approach is under implementation on the case-study
- Other case-studies are under analysis

23

The Future

- Test-Case generation for the TRMCS case-study
- Automation of ALTS-to-LTS step
- Uml & SA
- Traceability

- Uml and coordination Policies
- SA and Requirement Validation
- SA and Performance

24