Automatic adaptor synthesis for protocol transformation

Marco Autili, Paola Inverardi, and Massimo Tivoli

University of L'Aquila
Dip. Informatica
fax: +390862433057
via Vetoio 1, 67100 L'Aquila
{marco.autili, inverard, tivoli}@di.univaq.it

Abstract. Adaptation of software components is an important issue in Component Based Software Engineering (CBSE). Building a system from reusable or *Commercial-Off-The-Shelf* (COTS) components introduces a set of issues, mainly related to compatibility and communication aspects. Components may have incompatible interaction behavior. Moreover it might be necessary to enhance the current communication protocol to introduce more sophisticated interactions among components. We address these problems enhancing our architectural approach which allows for detection and recovery of integration mismatches by synthesizing a suitable coordinator. Starting from the specification of the system to be assembled and from the specification of the needed protocol enhancements, our framework automatically derives, in a compositional way, the glue code for the set of components. The synthesized glue code avoids interaction mismatches and provides a protocol-enhanced version of the composed system.

1   Introduction

Adaptation of software components is an important issue in Component Based Software Engineering (CBSE). Nowadays, a growing number of systems are built as composition of reusable or *Commercial-Off-The-Shelf* (COTS) components. Building a system from reusable or from COTS components introduces a set of problems, mainly related to communication and compatibility aspects [10]. In fact, components may have incompatible interaction behavior [4]. Moreover, it might be necessary to enhance the current communication protocol to introduce more sophisticated interactions among components. These enhancements (i.e. protocol transformations) might be needed to achieve dependability, to add extra-functionality and/or to properly deal with system's architecture updates (i.e. component aggregating, inserting, replacing and removing).

By referring to [9], many ad-hoc solutions can be applied to enhance dependability of a system. Each solution is formalized as a process algebra specification of communication protocol enhancements. While this approach provides a formal specification for a useful set of protocol enhancements, it lacks in automatic support in applying the specified enhancements.

In this paper, by referring to [9], we exploit and improve an existent approach [5, 8, 6] for automatic synthesis of failure-free coordinators for COTS component-based systems. The existent approach automatically synthesizes a coordinator to mediate the interaction among components by avoiding incompatible interaction behavior. This coordinator represents a starting glue code. In this paper we propose an extension that makes the coordinator synthesis approach also able to automatically transform the coordinator's protocol by enhancing the starting glue code. These enhancements might be performed to achieve dependability or to implement more complex interactions or to deal with system's architectural updates. This, in turn, allows us to introduce extra-functionality such as fault-tolerance, fault-avoidance, security, load balancing, monitoring and error handling into composed system. A modified version of the approach described in this paper has been applied to a more specific application domain than the general domain we consider. This is the domain of reliability enhancement in component-based system [3]. Starting from the specification of the system to be assembled, and from the specification of the protocol enhancements, our framework automatically derives, in a compositional way, the glue code for the set of components. The synthesized glue code avoids interaction mismatches and provides a protocol-enhanced version of the composed system. By assuming i) a behavioral description of the components and of the coordinator forming the system to be assembled and ii) a specification of the protocol enhancements needed on the coordinator, we automatically derive a set of new coordinators and extra-components to be assembled with the old coordinator in order to implement the specified enhanced protocol. Each extra-component is synthesized as a wrapper. A wrapper component intercepts the interactions corresponding to the old coordinator's protocol in order to apply the specified enhancements. It is worthwhile noticing that we might use existent third-party components as wrappers. In this case we do not need to synthesize them. The new coordinators are needed to assemble the wrappers with the old coordinator and the rest of the components forming the composed system.

Our approach is compositional in the automatic synthesis of the enhanced glue code. That is each enhancement is performed as a modular protocol transformation. This allows us to perform a protocol transformation as composition of other protocol transformations by impacting on the reusability of the synthesized glue code. For example if we add a new component or we replace/remove an existent component, we enhance the existent glue code by completely reusing it and by synthesizing a new modular glue code to be assembled with the existent one. The compose-ability, in turn, improves the space complexity of the old coordinator synthesis approach [5, 8, 6].

The paper is organized as follows. Section 2 introduces background notions helpful to understand our approach. Section 3 illustrates the technique concerning with the enhanced coordinator synthesis. Section 4 discusses future work and concludes.

2   Background

In this section, we provide the background needed to understand the approach illustrated in Section 3.

The reference architectural style: The architectural style we refer to, consists of a components and connectors style. Components define a notion of top and bottom side. The top (bottom) side of a component is a set of top (bottom) ports. Connectors are synchronous communication channel which define a top and a bottom role. A top (bottom) port of a component may be connected to the bottom (top) role of a single connector. Components communicate synchronously by passing two types of messages: notifications and requests. A notification is sent downward, while a request is sent upward. A top-domain of a component is the set of requests sent upward and of received notifications. Instead a bottom-domain is the set of received requests and of notifications sent downward. This style is a generic layered style. Since it is always possible to decompose a n-layered system in n single-layered sub-systems, in the following of this paper we will only deal with single layered systems. Refer to [5] for a description of the above cited decomposition. In Figure 1, we show a sample of a software architecture built by using our reference style.
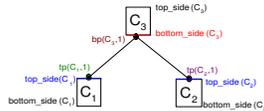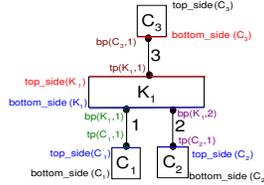

Fig. 1. An architecture sample

$bp(C_j, k)$ is the bottom port k of component C_j. $tp(C_j, h)$ is the top port h of component C_j.

Configuration formalization: We consider a particular configuration of the composed system which is called *Coordinator Based Architecture* (CBA). It is defined as *a set of components directly connected, through connectors, in a synchronous way to one or more coordinators*. It is worthwhile noticing that we use the style described in Section 2 to build a CBA. That is, a coordinator in a CBA is implemented as a component which is responsible only for the routing of messages among the others components. Moreover, the coordinator exhibits a strictly sequential input-output behavior[1]. All components (i.e. coordinators too) and system behaviors are specified and modelled as Labelled Transition Systems (LTSs). This is a reasonable assumption because from a standard incomplete behavioral specification (like *Message Sequence Charts* specification)

---

[1] Each input action is strictly followed by the corresponding output action.

of the coordinator-free composed system we can automatically derive these LTSs by applying the old coordinator synthesis approach. Refer to $[5, 8, 6]$, for further details. In Figure 2, we show a sample of a coordinator based software architecture built by using our reference style.

Fig. 2. A coordinator based architecture sample
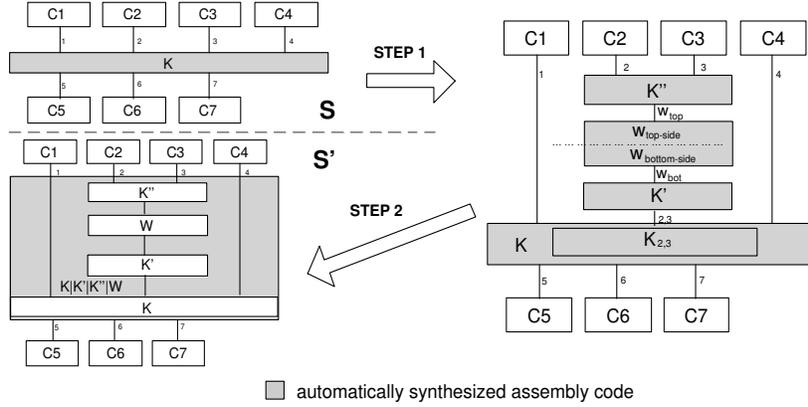
K_1 is the coordinator component.

3   Method description

In this section, for the sake of brevity, we informally describe our method. Refer to [2] for a formal description of the whole approach.

The problem we want to face can be informally phrased as follows: *given a CBA system S for a set of black-box components interacting through a coordinator K and a set of coordinator protocol enhancements E automatically derive the corresponding enhanced CBA system S'*.

We are assuming that a specification of the CBA system to be assembled is provided in terms of a description of components and coordinator behavior as LTSs. Moreover we assume that a specification of the coordinator protocol enhancements to be applied exists. This specification is given in form of *basic Message Sequence Charts* (bMSCs) and *High level MSCs* (HMSCs) specifications [1]. In the following, we discuss our method proceeding in two steps as illustrated in Figure 3.

In the first step, by starting from the specification of the CBA system, we apply the specified coordinator protocol enhancements to derive the enhanced version of CBA. We recall that we apply coordinator protocol enhancements by inserting a wrapper component between the coordinator in the CBA (i.e. K of Figure 3) and the portion of composed system concerned with the coordinator protocol enhancements (i.e. the set of $C2$ and $C3$ components of Figure 3). It is worthwhile noticing that we do not need to consider the entire coordinator model but we just consider the *"sub-coordinator"* which represents the portion of K that communicates with the components $C2$ and $C3$ (i.e. the *"sub-box"* $K_{2,3}$ of Figure 3). The wrapper component intercepts the messages exchanged between $K_{2,3}$, $C2$ and $C3$ and applies the specified enhancements on the interactions performed on the communication channels 2 and 3 (i.e. connectors 2 and 3 of Figure 3). We first decouple K, $C2$ and $C3$ to ensure that they are no longer

Fig. 3. 2 step method

directly synchronized. This is done by decoupling $K_{2,3}$, $C2$ and $C3$. Then we automatically derive a behavioral model of the wrapper component (i.e. a LTS) from the bMSCs and HMSCs specification of the coordinator protocol enhancements. We do this by exploiting our implementation of the technique described in [11] and also used in the old coordinator synthesis approach [5, 8, 6, 7]. Finally, the wrapper is interposed between the *top-side* of $K_{2,3}$ and the *bottom-side* of C_2 and C_3 by automatically synthesizing two new coordinators K' and K''. We do this by exploiting the coordinator synthesis approach formalized and developed in [2].

In the second step, we derive the implementation of the synthesized glue code formed by composing the wrapper component, with the old and new synthesized coordinators (i.e. W, K, K'' and K' of Figure 3 respectively). This code represents the coordinator in the enhanced version S' of the CBA system S (i.e. the coordinator $(K \mid K' \mid K'' \mid W)$ in system S' of Figure 3). By referring to Figure 3, the enhanced coordinator $(K \mid K' \mid K'' \mid W)$ in S' may be treated in the same way of the old coordinator K in S with respect to the application of the new coordinator protocol enhancements. This allows us to achieve composeability of different coordinator protocol enhancements (i.e. different protocol's transformations). In other words, our approach is compositional in the automatic synthesis of the enhanced glue code.

3.1 Application example

In this section, by means of an explanatory example, we show the processed steps of our method. In Figure 4, we consider a CBA system and its specification. Moreover in Figure 5, we consider the specification of the coordinator protocol enhancements.
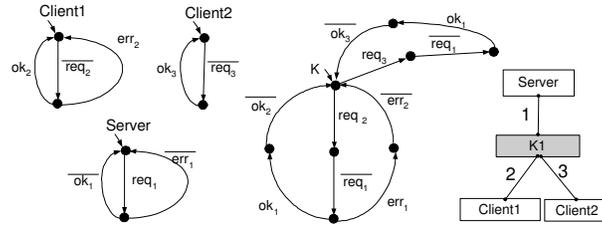
Fig. 4. A Client-Sever CBA system and its specification
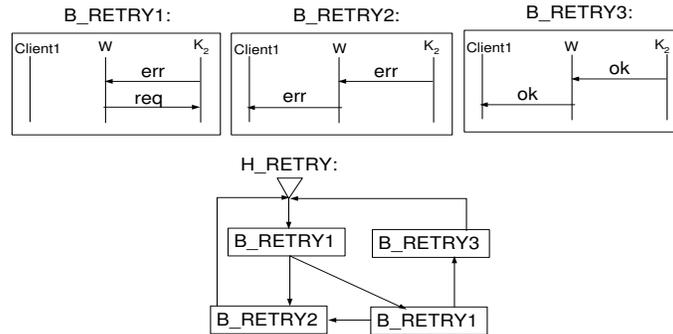
Fig. 5. The *bMSCs* and the *hMSC* of the coordinator protocol enhancements: *retry* policy

$Client1$ performs a request and waits for a response: erroneous or successful[2]. *Server* may answer with an error message (the error could be either due to an upper-bound on the number of request *Server* can accept simultaneously or due to a general transient-fault). Now, let $Client1$ be an interactive client and once an error message occurs, it shows a dialog window displaying information about the error. The user might not appreciate this error message and he might lose the degree of trust in the system. By recalling that the dependability of a system reflects the users degree of trust in the system, this example shows a commonly practiced dependability-enhancing technique. The wrapper attempts to hide the error to the user by re-sending the request a finite number of times. This is the *retry* policy specified in Figure 5. The wrapper W re-sends at most two times.

K_2 is the "*sub-coordinator*" which represents the portion of K1 communicating with $Client1$. Its "*real*" behavior is described by the so called *Bottom domain Actual Behavior Graph of the $K1$ coordinator, $KBAC_2$, restricted to the Client1 component* (the LTS in Figure 6). This graph is obtained by filtering the LTS specification of K1. This is done by using the algorithm formalized in [2]. Then we automatically derive a behavioral model of K_2 (i.e. a LTS) from the bMSCs and HMSCs specification of the *retry* police. If this model differs from the "*real*"

---

[2] The transitions labelled with α_i denote input actions while the transitions labelled with $\bar{\alpha}_i$ denote output actions on the communication channel i (i.e. the connector i).
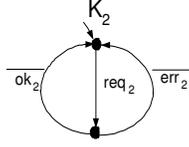
Fig. 6. *Bottom domain Actual Behavior Graph, $KBAC_2$, of the $K1$ coordinator*

behavior then the enhancement cannot be performed because its specification does not "*reflect*" the behavior of K1; otherwise, we first automatically derive the LTS specification of the wrapper W and then we insert it between K (i.e. K_2) and the top-side of $Client1$. This is done by automatically synthesizing two new coordinators: K2 and K3 (Figure 7). The wrapper inserting procedure is formalized in [2].
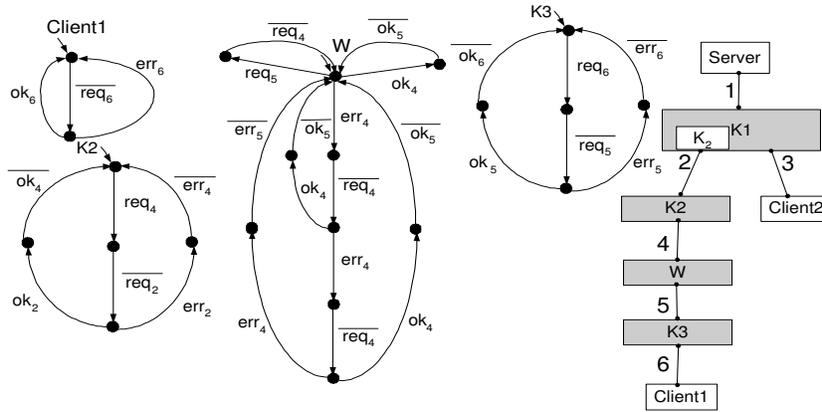

Fig. 7. Enhanced version of the *Client-Server* system.

4   Conclusion and future work

In this paper we propose and briefly describe an extension of the approach presented in [5, 8, 6]. The extension is performed to make the old approach able to achieve compose-ability and to deal with both problems in the area of dependability enhancement and problems raised by system's architecture updates. We have formalized the whole approach. Refer to [2] for details about the formalization of the approach.

The key results are: i) the extended approach is compositional in the automatic synthesis of the enhanced coordinator, ii) by achieving compose-ability, we improve the space complexity of the old coordinator synthesis approach [5,

$8, 6]$ and iii) the enhanced coordinator is adequate with respect to *data translation, components inserting, removing and replacing, monitoring, error handling, security, dependability enhancement.*

The automation and applicability of the old coordinator synthesis approach [5, 8] is supported by our tool called *"SYNTHESIS"* [6]. As future work, we plan to: i) extend the current implementation of the *"SYNTHESIS"* tool to support the automation of the extended coordinator synthesis approach [2] presented in this paper; ii) think about a more user-friendly and real-scale context specification of the coordinator protocol enhancements (e.g. UML2 Interaction Overview Diagrams and Sequence Diagrams); iii) validate the applicability of the whole approach to real-scale examples.

References

1. Itu telecommunication standardisation sector, itu-t reccomendation z.120. message sequence charts. (msc'96). Geneva 1996.
2. M. Autili. Sintesi automatica di connettori per protocolli di comunicazione evoluti. Tesi di laurea in Informatica, Universitá dell'Aquila - http://www.di.univaq.it/tivoli/AutiliThesis.pdf, April 2004.
3. D.Garlan and M.Tivoli. A coordinator synthesis approach for reliability enhancement in component-based systems. *submitted for publication*, April 2004.
4. D. Garlan, R. Allen, and J. Ockerbloom. Architectural mismatch: Why reuse is so hard. *IEEE Software, 12(6), November*, 1995.
5. P. Inverardi and M. Tivoli. *Software Architecture for Correct Components Assembly - Chapter in: Formal Methods for the Design of Computer, Communication and Software Systems: Software Architecture - Editors: Marco Bernardo and Paola Inverardi.* Springer, September 2003.
6. M.Tivoli, P.Inverardi, V.Presutti, A.Forghieri, and M.Sebastianis. Correct components assembly for a product data management cooperative system. In *proceedings of the International Symposium on Component-based Software Engineering (CBSE7) an adjunct event to ICSE2004 workshops*, May 24-25 2004.
7. P.Inverardi and M.Tivoli. Automatic failures-free connector synthesis: An example. *Radical Innovations of Software and Systems Engineering in the Future, 9th International Workshop, RISSEF2002, Venice, Italy*, LNCS 2941.
8. P.Inverardi and M.Tivoli. Connectors synthesis for failures-free component based architectures. University of L'Aquila, Computer Science Department. Technical Report, January 2004. Submitted for publication.
9. B. Spitznagel and D. Garlan. A compositional formalization of connector wrappers. In *proceeding of the 25th IEEE International Conference on Software Engineering (ICSE'03) - Portland, OG (USA)*, May 2003.
10. C. Szyperski. *Component Software. Beyond Object Oriented Programming.* Addison Wesley, Harlow, England, 1998.
11. S. Uchitel, J. Kramer, and J. Magee. Detecting implied scenarios in message sequence chart specifications. In *ACM Proceedings of the joint 8th ESEC and 9th FSE*, Vienna, Sep 2001.