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Reconfigurable Service-Based Architecture Based on Variability Description

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ABSTRACT

Self-adaptive systems evolve during system’s execution against changes in operating environment. Such evolution and reconfiguration can be specified at architecture level using a syntactical expressive language such as Architecture Description Languages (ADLs). Variability modeling is an excellent instrument to model variations of software artifacts and their behavior within a self-adaptive system. However, existing ADLs that support dynamic reconfiguration do not explicitly model variation points on which the reconfiguration is based. This constitutes a barrier for a flexible management of reconfiguration at architecture level as well as traceability issues between a dynamic description given at architectural level and its counterpart at other abstraction levels. In this paper, we propose a variant-rich service-oriented ADL that enables system to reconfigure itself at runtime in response to a context change. To this end, our modular ADL, called Dynamic Service-Oriented Product Lines Architecture Description Language (DSOPL-ADL), specifies dynamic reconfigurations at architecture level besides specifying structural, variability and context information. Among several specified variable configurations at architecture level, one concrete configuration is generated at runtime triggered by a context value. Furthermore, an implementation code can be automatically generated from the architectural description.

CCS Concepts

• Software and its engineering → Software architectures; Software development process management;

Keywords

Architecture Description Language (ADL); variability; dynamic reconfiguration; architecture-centric reconfiguration; self-adaptive service-based systems; context-aware

1. INTRODUCTION

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It may happen that software architecture needs to evolve after its deployment [8]. Such an architecture is considered dynamic, since it can modify itself and adopt modifications during system’s execution [5]. This is a required property in systems where stopping the execution to make modifications on it might cause dramatic effects. Relying on dynamic architecture can be useful in self-configurable systems. Self-configurable (or self-adaptive) systems aim to adapt their various artifacts autonomously as well as change their configuration dynamically in response to changes in the operating environment (i.e. context changes) without human interaction [7], [12], [10]. Dynamic adaptive systems are used in different domains of application such as natural catastrophe prevention (e.g. flood warning), traffic control system, e-commerce applications.

Reconfiguration can be specified at architecture level using an Architecture Description Language (ADL). ADL is a formalism that allows the specification of system’s conceptual architecture [19]. It describes a high-level structure of the system rather than implementation details. Conventional ADLs support only static architecture description [18], [9]. Some ADLs, however, support dynamic architecture description, such as [17], [4], [18], [14], [13], [21].

Dynamic reconfiguration of software artifacts is often discussed only at implementation level. Such a late reconfiguration hinders the traceability of configuration and consistency between different levels of the software development life cycle. However, there are some approaches that discuss reconfiguration issues at early stages of development process, for example at architecture or design levels, such as [4], [14], [18]. In these approaches, reconfiguration is expressed in an ad-hoc manner; reconfiguration is described without any explicit identification and separation of concerns. This makes the configuration description hard to understand and the reconfiguration hard to implement. It also hinders a full management of dynamic reconfiguration at architecture level. Moreover, it constitutes a challenge to trace dynamic reconfiguration description/management at different levels of abstraction.

In this paper, we propose to specify a dynamic reconfiguration at architecture level based on variability description. Variability modeling allows an explicit specification of configurable artifacts. More precisely, we extend our previous proposition of a modular ADL called Dynamic Service-Oriented Product Lines Architecture Description Language (DSOPL-ADL) [2] by enriching the static description with dynamic reconfiguration specifications. This enables a dynamic self-reconfiguration of system at runtime in response
to a context change. Moreover, we propose a process that generates, among several variable configurations described in reference architecture, a concrete configuration that satisfies context values. Furthermore, we automatically generate an executable implementation code from our concrete architectural description.

The rest of the paper is organized as follows: in section 2, we briefly present the modular Dynamic Service-Oriented Product Lines Architecture Description Language (DSOPL-ADL) through an illustrative example. In section 3, we present our approach of self-reconfigurable architecture description based on variability information. In section 4, we show how we can generate a concrete architecture and how to transform it to an executable language. Before concluding, in section 5, we present related work that propose ADLs that comprise dynamic description of reconfiguration.

2. BACKGROUND

2.1 Illustrative Example

We will use an illustrative example to demonstrate concepts related to our proposed approach. This example is about a simplified on-line sales scenario between four services; customer, retailer, warehouse and shipping, as illustrated in figure 1. The customer can access retailer’s website, browse the catalog, select some items and command an order. The retailer fulfills customer’s order request and inquires the warehouse to prepare all items of the order. Once the order is prepared, the shipping service handles the delivery of items to the customer in question.

![Figure 1: Illustrative example: On-line sales scenario architecture](image)

2.2 Variability-Based Static DSOPL-ADL

DSOPL-ADL is a service-based and variant rich description language that specifies four main types of architectural information: (i) structural description, which specifies the architecture in terms of its structural artifacts, (ii) variability description defines variation points and alternatives on which system’s configuration is based, (iii) context information, to which service configurations adapt and (iv) configuration description describes possible static configurations based on context and variability information.

As structural description, we represent architecture’s main artifacts in terms of services, interfaces and their provided operations. A service is an encapsulated unit that interacts with other services through interfaces. Each service has a number of provided interfaces and may consume a number of required interfaces. Interfaces define a number of operations that are provided by the service. The system is hierarchically decomposed into finer-grained services. A composite service does not execute or implement any functionality by itself, but it delegates its task to one of its child services called atomic services. Listing 1 shows a part of the structural description related to our illustrative example. We can notice that "retailer" and "warehouse" services are atomic services of the composite service "supply chain management". "Retailer" service has two interfaces; one provider interface named i_order, which provides two operations and one consumer interface named i_goods_request.

![Listing 1: Structural Description of Sales Scenario](image)

In addition to structural description, in DSOPL-ADL, we handle variability information as first-class elements. In variability description, we distinguish three types of variability: (i) service variability, where a variation point specifies different available alternative services (ii) connection variability, since two services can be differently connected to each other according to constraint’s satisfaction and (iii) composition variability, where a set of interconnected services may vary, thus the importance to specify such a variability type.

As an example of variability description, we demonstrate in listing 2 a service variability. Here, the abstract "shipping" service is a variation point and has two alternative services; either a "relay point" shipping or "home delivery" shipping. During system execution, one of these alternatives and upon condition satisfaction, replaces the abstract "shipping" service.

![Listing 2: Service variability description example](image)
Context elements need to be described in a self-adaptive architecture. Therefore, we include context description as first-class architectural elements to allow context-aware configurations (i.e., autonomous adaptation according to context changes). A context could either be primitive or composite (several primitive context information contribute to provide a complex context information).

3. DYNAMIC ARCHITECTURE DESCRIPTION BASED ON VARIABILITY DESCRIPTION

In systems where its environment remains unchanged during system execution, a static ADL that describes system’s structural and behavioral specifications could be sufficient. In static ADL, architecture’s configuration description allows specifying all available configuration rules. However, one valid configuration can be selected at design time and it can not be reconfigured during execution. Reconfiguration specification in DSPOL-ADL is here discussed where a dynamic architecture is specified based on variability description.

3.1 Behavioral Activities

To capture the reconfiguration aspect of a dynamic architecture, we first represent the different inter-service communications (i.e., message flows) which are realized through message passing. Architectural behavior is based on three activities:

1. **receive**: In this type of uni-directional communication, a consumer service (i.e., client) sends a message to the service provider without expecting any instant response. Consequently it only specifies an input message and requires no output message. The receive element specifies the consumer service using consumer_instance attribute and its interface using consumer_interface attribute. It also specifies the service provider through provider_instance attribute and its interface provider_interface. The consumer service triggers the execution of a specific operation at the provider’s side which is specified in the operation attribute. Finally, the arguments passed to the operation are carried on input_message attribute.

2. **respond** communication is used to reply to a message that was previously received through a receive communication. In that case, values of consumer_instance, consumer_interface, provider_instance and provider_interface attributes match the same attributes’ values of the corresponding receive communication. The response message is passed on the output_message attribute.

3. **invoke**: In this type of communication, the service provider receives a message from the service consumer and should in his turn respond by a message. The receiving message is carried on input_message, whereas the response is returned on output_message. In order to invoke a provider service, the bi-directional

![Figure 2: Configuration description meta-model of DSPOL-ADL](image)

In order to specify architecture’s common configuration and its variable (re-)configurations, we distinguish two sections in DSPOL-ADL configuration description: (i) a common configuration description part, where common services of the architecture are instantiated and bound with a certain behavior and a (ii) variable configuration description part, where partial configurations describe the behavior of variation points. Next, each of these parts are detailed. Figure 2 presents the meta-model of configuration description.

3.2 Common Configuration Description

Common configuration description section contains two subsections: **initialization** and **behavior**. The initialization sub-section describes the entire structural information about the common services of the architecture. Here, all common services (i.e., those that are not subject to variability) are instantiated and bound. Deployable service instance is used to create an instance from a particular service. The binding part has two references to two different service interfaces, the one that calls an operation consumer_interface and the one that provides the operation provider_interface.

In the behavior sub-section, we describe the workflow of the entire architecture and mask the parts of the architecture that are subject to variability. The workflow is described in form of a sequence of communication activities (receive, respond and invoke) between services. In each communication activity, we identify the direction of flow by identifying consumer and provider instances as well as specifying the interfaces that will communicate from each side of consumer and provider instances in order to execute a particular operation.

3.3 Variable Configuration Description
The second part of the configuration description is the *variable configuration description* which contains several *partial configurations*. Each partial configuration refers to an alternative point that is defined in the variability description module of DSOPL. A variable partial configuration is triggered by conditions. Any *partial configuration* has two parts, as also demonstrated in listing 3:

1. *condition* part: where we specify the condition that is driven by context elements. Once the condition satisfied, a given behavior is selected to integrate the existing architecture. In case several conditions of different alternatives of the same variation point are satisfied, the alternative with the higher priority is privileged.

2. *behavior* part: where we specify all dynamic activities that will be executed in order to let the concerning alternative integrate the existing architecture.

The specification of DSOPL-ADL reconfiguration description is given in listing 3. We choose to specify it in REgular LAnguage for XML, New Generation (RELAX NG) [6], an OASIS standard schema language for XML. Relax NG comes in two versions; an XML syntax version and a compact non-XML syntax version. We choose to specify the DSOPL-ADL configuration description using RELAX NG compact version due to its simplicity and expressiveness; unlike other schema languages (e.g. XML Schema) it has a clean formal model.

Back to our example, both "customer" and composite "supply chain management" services make part of the common architecture, since they are not subject to any variation. This implies that their instantiations and bindings can be specified at design time, as depicted in the *common configuration description* part of listing 4. Whereas shipping services "relay point" and "home delivery", which are alternatives of abstract "shipping" service, are dynamically instantiated at runtime to replace the abstract "shipping" service. This is why their instantiation and behavior are specified in the *variable configuration description* part.

Listing 3: Configuration description Specification

```xml
<configuration_description>
  <element configuration_description {  
    <element common_configuration_description {  
      <element initialization {  
        <services {  
          <element deployable_service_instance {  
            <attribute service,  
            <attribute service_instance }  
          }  
        }  
        <bindings {  
          <element binding {  
            <attribute consumer_instance,  
            <attribute consumer_interface,  
            <attribute provider_instance,  
            <attribute provider_interface }  
          }  
        }  
      }  
      <element variable_configuration_description {  
        <element partial_configuration {  
          <element condition {  
            <element context {  
              <attribute name,  
              <attribute value }  
            }  
            <element behavior {  
              <services,  
              <bindings,  
              <invoke | receive | respond }  
            }  
          }  
        }  
      }  
    }  
  }  
</configuration_description>
```

Listing 4: Configuration description of sales scenario

```xml
<configuration_description>
  <initialization>
    <services>
      <deployable_service_instance service_instance="customer_service_instance" service="customer_service"/>
      <deployable_service_instance service_instance="supply_chain_management_service_instance" service="supply_chain_management_service"/>
    </services>
    <bindings>
      <binding consumer_instance="customer_service_instance" consumer_interface="customer_service" provider_instance="supply_chain_management_service_instance" provider_interface="i_order_delegation"/>
    </bindings>
  </initialization>
  <behavior>
    <receive name="receive_customer_request" consumer_instance="customer_service_instance" consumer_interface="i_customer_order" provider_instance="supply_chain_management_service_instance" provider_interface="i_order_delegation" operation="prepare_order" input_message="receive_order_items"/>
    <respond name="send_order_details" consumer_instance="customer_service_instance" consumer_interface="i_customer_order" provider_instance="supply_chain_management_service_instance" provider_interface="i_order_delegation" operation="prepare_order" output_message="out_order_details"/>
  </behavior>
  <partial_configuration>
    <variable_configuration_description>
      <condition>
```

In the <initialization> part of <common_configuration_description>, “customer” and “supply chain management” services are bound together through their interfaces in the <binding> part, as depicted in listing 4. In the <behavior> part, the workflow starts by a trigger activity from the “customer” service, which makes a sales order. The “supply chain management” service receives the ordered items through the <input_message> = “in_ship_order” of <receive> activity and executes the operation <operation> = “prepare_order”.

Next, a <decision_point> indicates the existence of a variation point with a reference to the “shipping_variation_point” which is explicitly defined in the variability description part of DSOPPL-ADL. The <decision_point> part of the behavior will not be executed at design time but at runtime. The different partial configurations related to each variation point are described in the <variable_configuration_description> part of the configuration description of DSOPPL-ADL. All related instructions of instantiating and binding either “home delivery shipping” service or “relay point shipping” service will be performed only at run-time according to the context value of “shipping” in the <condition> part of each <partial_configuration>. Once the corresponding shipping service is bound, “supply chain management” service will invoke one of these shipping services and execute either “order_delivery_to_home” or “order_delivery_to Relay_point” operations. Obviously, information about ordered items are passed from the “supply chain management” service to selected shipping service through the message <input_message> = “in_ship_order”. Likewise, shipping information (such as shipping delays and costs) are returned through the message <output_message> = “out_ship_order”.

Finally, as a response to customer’s initial order request, the “supply chain management” service executes the “prepare_order” operation and sends the order details to the “customer” service through an <output_message> = “out_order_details” within a <respond> activity. Here, both service instances (consumer_instance and provider_instance) as well as their interfaces (consumer_interface and provider_interface) are the same of the <receive> activity, since it is a respond to that request.

4. ARCHITECTURE CENTRIC RECONFIGURATION OF SERVICE-BASED SYSTEM

4.1 Concrete Architecture Generation

A concrete configuration of architecture is generated from a given reference architecture’s <configuration_description> through the following consecutive steps:

1. The <common_configuration_description> part of the configuration description is copied to the concrete configuration description of architecture without any modifications, except copying <decision_point> part which is treated differently in step 2.

2. Each variation point called <decision_point> in the <common_configuration_description> part of DSOPPL-ADL is replaced by an appropriate <partial_configuration> according to context value satisfaction of that partial configuration.

3. Consequently, all service instances related to that partial configuration in addition to their bindings both described in <services> and <binding> sub-sections of <partial_configuration> are integrated to the concrete architecture to <services> and <binding> sections, respectively.

Figure 3 demonstrates how a concrete architecture is generated in on-line sales example after integrating a partial configuration (here, relay point delivery shipping service) to the common configuration part.

4.2 Executable Code Generation

In this section, we demonstrate how an executable business process can be obtained based on the generated DSOPPL concrete architecture. Among existing business process specification languages, we choose to generate DSOPPL’s concrete architectural description in Business Process Execution Language (BPEL), since it is the most dominant language [11] and has become a de-facto standard for specifying workflow in a service-oriented environment and hence executing business processes for web services composition [3]. BPEL defines in principle two main types of activities: basic activities to interact with external services (invoke, receive, reply) and structural activities to control the internal business workflow by conditional choices, parallel activities and looping.
The most challenging part of BPEL’s code generation is the transformation of DSOPL-ADL’s behavior into BPEL’s activities due to the difference of workflow realization between both paradigms. Conceptually, there are two different perspectives of realizing a workflow: choreography and orchestration. In choreography, the configuration is realized between autonomous peer-to-peer collaborations, whereas in orchestration a single central workflow engine coordinates the execution flow between all involved Web services. In DSOPL-ADL, configuration is specified following the choreography perspective; i.e. configuration is realized through message passing from one service to another one without intermediaries. Figure 4 demonstrates the sequence of activities for the sales order concrete architecture example.

According to the mapping rules presented in Table 1, the sequence of activities in the concrete architecture of on-line sales order example (represented graphically in figure 4) is transformed to BPEL activities as demonstrated in figure 5. We can notice that a new actor is added in BPEL called "Sales Order Process" which is a central process that coordinates the message passing and order of flow between services called "Partner Links". This central process must be either a consumer or provider part in all BPEL activities, this explains why each DSOPL-ADL activity is mapped to one or more activities in BPEL. The "receive" activity in DSOPL-ADL (designated by number 1), which receives customer’s order and prepares it, is represented by four activities in BPEL: receive, assign_customerRequest, invoke_prepareOrder and assign_orderInformation (all designated by number 1 in figure 5). The bi-directional activity "invoke" in DSOPL-ADL (designated by number 2 in figure 4) is transformed to two activities in BPEL: invoke_OrderDeliveryToRelayPoint and assign_CustomerOutput. This latter copies the content of returned message from relay_point_delivery_shipping_service and assigns it to a local temporary variable. Finally, the "respond" activity (designated by number 3 in figure 4), which is in charge to return order’s confirmation and information about shipping to the customer, is transformed to the "reply" activity in BPEL (designated by 3 in figure 5).

Due to space limitation, we do not demonstrate the entire BPEL code, but only one behavior transformation. In the sequence section, the transformation result of <receive> activity is demonstrated in listing 5. It is composed of four sequential activities: <receive>, <assign>, <invoke> and <assign>.
6. CONCLUSION AND PERSPECTIVES

We have presented an architecture description language that allows the reconfiguration at runtime of a software architecture based on variability description. To manage the
runtime reconfiguration at architecture level, we have extended a previous work called DSOPL-ADL which described static structural, variability and context elements and extended it with dynamic reconfiguration aspect. For that purpose, we presented a reconfiguration description meta-model as well as the language schema. During system’s execution, architecture can adapt its behavior to environment changes that are specified as context elements and consequently generate a concrete architecture. Furthermore, we transformed generated concrete architecture to another level of abstraction such as to business process level (i.e. to BPEL).

7. REFERENCES


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<td>Y</td>
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