Incremental Integration of Microservices in Cloud Applications

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Abstract

Microservices have recently appeared as a new architectural style that is native to the cloud. The high availability and agility of the cloud demands organizations to migrate or design microservices, promoting the building of applications as a suite of small and cohesive services (microservices) that are independently developed, deployed and scaled. Current cloud development approaches do not support the incremental integration needed for microservice platforms, and the agility of getting new functionalities out to customers is consequently affected by the lack of support for the integration design and automation of the development and deployment tasks. This paper presents an approach for the incremental integration of microservices that will allow developers to specify and design microservice integration, and provide mechanisms with which to automatically obtain the implementation code for business logic and interoperation among microservices along with deployment and architectural reconfiguration scripts specific to the cloud environment in which the microservice will be deployed.

Keywords: Microservices, incremental, integration, cloud, cloud architectures

1. Introduction

The need to maintain high customer satisfaction by delivering new or customized products and services signifies that development paradigms are changing to the Continuous Integration (CI) and Continuous Deployment (CD) of software functionality, in which companies offering internet-based services should be capable of providing customers with software functionality on a daily basis [9]. The microservice architectural style has therefore emerged to facilitate CI/CD by affecting the way in which software development teams are structured, source code is organized and continuously built/packed, and software products are continuously deployed [8]. This architectural style proposes the development of a single application as a suite of small and cohesive sets of microservices built around business capabilities, and independently developed, deployed and scaled, thus allowing them to scale their applications, gain agility and get new functionalities out to customers faster [10], [17].

The flexibility in resource management (e.g. processing, memory, message queues) provided by cloud environments is motivating organizations to consider them as their system deployment environment, in which different Infrastructure as a Service (IaaS) or Platform as a
Service (PaaS) environments are chosen depending on the Service Level Agreement (SLA) or other requirements. Cloud environments are a well suited option as regards deploying microservices [14], [2], since they allow companies to gain agility and reduce complexity not only when deploying and scaling microservices, but also by acquiring resources provisioned according to specific microservice needs. However, applications that will be deployed in cloud environments (cloud applications) must be developed using cloud-specific standards, thus preventing developers from creating software that can be deployed on multiple clouds, which is known as vendor lock-in [6]. The incremental nature of the microservice-based applications development additionally leads to a situation in which the application’s architecture evolves each time a microservice is integrated into it. Building microservices for deployment in cloud environments therefore requires managing architectural changes (architectural reconfiguration) and minimizing application disruptions while the integration takes place.

Current cloud development approaches do not support microservice development/migration and only a few technical reports on this can be found (e.g., [2], [16], [19]). Approaches that support the development of cloud applications are related to this work (e.g., [11], [12], [1]); however, proposals confronting the incremental development and its architectural implications are still lacking. Furthermore, in terms of architectural reconfiguration, as far as we know, there are no proposals that support a systematic reasoning about the architectural impact of the integration of services included in a given software increment into the current application architecture. In previous works [23],[25], we introduced a general process definition for the DIARy method which follows an incremental and MDD approach that supports the incremental integration of cloud service applications and their dynamic architecture reconfiguration triggered by the integration of new software increments (hereafter referred to as increments); to support the specification and generation of some software artifacts for service architecture reconfiguration. In this paper, we extend the DIARy process by defining new activities and tasks to satisfy microservices principles and support the incremental integration of microservices. We also provide the tool support needed to automate these tasks by defining the metamodels, which define the microservice integration logic, as well as the transformation chains, which automate the generation of software artifacts that implement the integration logic (orchestration among microservices), and scripts for architectural reconfiguration.

The remainder of this paper is structured as follows. Section 2 contains a description of the background and discusses related works. Section 3 presents an overview of the method proposed. Section 4 illustrates the use of our approach in a case study. Finally, Section 5 presents our conclusions and future work.

2. Background and Related Work

The microservice architectural style is a lightweight subset of the Service Oriented Architecture (SOA), in which: “the main difference between SOA and microservices is that the latter should be self-sufficient and deployable independently of each other while SOA tends to be implemented as a monolith” [21]. This architectural style is gaining acceptance as regards overcoming the shortcomings of a monolithic architecture in which, rather than having the application logic within one deployable unit, applications are decomposed into services, each of which is deployable on a different platform, runs its own process, and communicate by means of lightweight mechanisms. The main principles of microservices are [10]:

1. **Componentization via Services**: Software is broken up into multiple services that are independently replaceable and upgradeable and communicate by means of inter-process communication facilities using an explicit component-published-interface.

2. **Organized Around Business Capabilities**: Microservices are implemented around business areas, in which services include a user-interface, storage, and any external collaborations.

3. **Products not Projects**: Development teams own a product throughout its entire lifetime, taking full responsibility for the software in production.
4. **Smart Endpoints and Dumb Pipes**: Business logic, related business rules, and data reside in the services themselves rather than in a centralized middleware. Simple messaging or a lightweight messaging bus is used to provide communication among microservices.

5. **Decentralized Governance**: Standardization on a single technology platform is avoided; the right technological stack for a job should be used, and each microservice manages its own decisions regarding tools, languages, and data storage.

6. **Decentralized Data Management**: Decisions concerning both the conceptual model of the world and data storage will differ between microservices.

7. **Infrastructure Automation**: Automatic means to integrate and deploy in new environments.

8. **Evolutionary Design**: Services are independently replaced and upgraded, which is achieved by using service decomposition as a tool so as to enable application developers to control changes in software applications at the pace of business changes.

**Decentralized Governance** and **Decentralized Data Management** microservice principles suggest avoiding standardization in a single technology; however, certain development challenges (e.g., the **vendor lock-in**) need to be addressed in order to produce services that are feasible for deployment in different cloud environments. Furthermore, the **Infrastructure Automation** microservice principle suggests having an automatic means of integration and deployment in new environments. However, despite the fact that development teams building microservices use CI/CD techniques and tools [10], these techniques require the inclusion of reliable software artifacts (e.g., implementation code, deployment scripts, configuration scripts) in their automated building processes or deployment pipelines. Software artifacts should therefore be error free in order to ensure that the CI/CD’s automated test functionalities do not prevent the integration or deployment process. Finally, CI/CD requires the making of architectural decisions [21], and in a context in which the application architecture evolves with each microservice integration, mechanisms that support the specification of architectural decisions and manage architectural changes without preventing the execution of applications are therefore required.

**Model-Driven Development (MDD)** is an approach used to develop software systems in which developers build an application by refining models at different levels of abstractions, and then obtain implementation artifacts by means of model transformations. We believe that an MDD approach provides good support as regards managing microservice integration and the consequent architectural evolution of the application. This approach will allow developers to: i) capture technology-independent microservice integration specification and deployment information, thus making design artifacts reusable and enabling developers to overcome the **vendor lock-in** issue; ii) propagate microservice integration specification to implementation/deployment/reconfiguration artifacts, thus enabling developers to obtain error free artifacts; and iii) automate building, packaging, deployment and the architectural reconfiguration process.

**Related Work**

Developing applications by using the microservice architectural style is a relatively new approach, and only a few related technical reports can be found (e.g., [2], [16], [19]). These works describe design decisions made or strategies employed in order to either satisfy microservice principles, or make use of CI/CD tools and techniques; however, they do not propose design, implementation or integration methods. Moreover, those works do not propose mechanisms with which to help obtain error free artifacts to be included into CI/CD pipelines.

Microservices are cloud-native architectures, and the MDD approaches that support the development of cloud applications are therefore related to this work (e.g., [12], [11], [1], [20]). These approaches apply MDD principles in order to tackle the **vendor lock-in** problem when developing or migrating cloud applications. With regard to approaches that propose mechanisms with which to document design decisions in cloud environments we can highlight CAML [3], MULTICLAPP [13] and CloudML [4]. These works define UML profiles or other modeling languages used to describe deployment topologies, applications as a composition of software artifacts to be deployed across multiple clouds, or resources that a given application

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may require from existing clouds. However, although “getting integration right is the single most important aspect of the technology associated with microservices” [17], these proposals do not provide mechanisms with which to specify architectural decisions regarding integration and the impact of integrating increments in the current cloud application architecture. Finally, with regard to approaches for dynamic reconfiguration, works such as SeaClouds [5] or MODAClouds [1] propose mechanisms that can be used to achieve architectural reconfiguration either by replacing orchestration or as result of the re-deployment of components. These proposals do not allow the specification of the architectural changes produced during integration nor do they take into account implementation alternatives that facilitate scalability and the re-deployment of services in different clouds.

3. A Method for the Incremental Integration of Microservices

This method allows cloud applications to be constructed as a composition of microservices, in which each microservice design is included in an incremental increment integration process that allows developers to specify how microservices will be integrated into a cloud application. Developers use the increment integration specification to generate software artifacts, such as skeletons of microservice logic, interaction protocol and scripts with which to build, deploy and architecturally reconfigure the current cloud application, all of which are generated according to each microservice technology specification. In order to define this method, we analyzed how our previous work satisfies the principles of the microservice architectural style; we then used the lessons learned to extend the DIARy-process [23],[25]. The Microservice Incremental Integration Method, which is made up of the Microservices Incremental Integration Process (also referred to as the Integration Process), the adapted DIARy-specification-profile [24] and transformation chains, is explained as follows. Fig.1 shows the Integration Process, whose main activities are explained in the next sections:

Fig.1. The Microservice Incremental Integration Process

Increment Integration Specification

This activity aims to allow developers to specify how to integrate an increment into the current application (Application Architecture Model) by specifying both the integration logic and the architectural impact of integration without taking into consideration the specifics of any cloud environment. In this activity, developers take a microservice (Microservice Architecture Model) as input, include it as part of an increment, follow Increment Integration Specification Guidelines, and make integration design decisions based on SLA terms (whose definition, specification and representation is outside of this work scope). Since this is an iterative activity, it provides developers with the possibility of specifying the integration of increments composed of several microservices. The DIARy-Specification-profile (see [24] for more details about its usage) helps developers create the Extended Increment Architecture Model which describes the increment specification integration by documenting the increment’s architecture, the integration’s logic and the architectural impact of integration. This model complies with the Extended Increment Architecture Model metamodel, which is explained below.
The Extended Increment Architecture Model metamodel

The Service oriented architecture Modeling Language (SoaML) [18] is an OMG specification that was specifically designed for the modeling of service-oriented architectures. SoaML leverages the Model Driven Architecture (MDA) and provides a UML profile and a metamodel that extends the UML metamodel. The DIARy-specification-profile extends the SoaML profile, resulting in an ADL that facilitates the increment integration specification. In order to facilitate software artifact generation, this work extends SoaML and UML metamodels in order to define the Extended Increment Architecture Model metamodel (see Fig. 2). Owing to space limitations, Fig. 2 includes only those meta-classes that define the main concepts used to describe integration logic and architectural impact, in which meta-classes belonging to the UML metamodel are depicted with an icon next to the meta-class name, whereas meta-classes that extend the SoaML/UML notations are depicted with a background color.

Fig. 2. Extract of Increment Architecture Model meta-model

A Participant represents: i) a microservice to be integrated, ii) a microservice/component already existing in the current Application Architecture Model with which the microservice(s) to be integrated will interoperate, and iii) a microservice/component to be created in order to consume microservice services or provide it with services.

The Services Architecture of the participant is modeled as SoaML Services Architecture diagrams and specifies how parts of a microservice work together to play the owning microservice role(s). This diagram includes the microservice’s inner architectural elements and its interoperation requirements.

An Extended Increment Architecture extends a UML Collaboration, thus allowing the increment integration specification by describing both the integration logic and the architectural impact of integration. Its inner parts (ParticipantUse, RoleBindings, and ServiceContractUse) describe an architecture: the increment’s architecture. Each ParticipantUse is a reference to a Participant involved in the integration. Each ServiceContractUse is a reference to a ServiceContract that describes interoperation among Participants. RoleBindings, and ServiceContractUses define the integration logic, whereas tagging ExtendedIncrementArchitecture inner parts with architecturalImpact values defines the architectural impact of integration.

A ServiceContract extends a UML Collaboration. When modeling the Services Architecture of the participant, its semantic remains the same as that defined by SoaML. When modeling the integration (ExtendedIncrementArchitecture), it describes specific roles that Participants will play. Roles have a name and an Interface type that specify operations and events, which comprise the interoperation Interactions among Participants after integration.

A ParticipantUse is a Participant involved in a specific integration, where the delayLevel attribute makes it possible to specifying whether the Participant requires immediate processing of requests or whether they could be delayed by using cloud environment services (e.g., message queues). The elasticityLevel attribute allows the specification of requirements concerning the level of the Participant scaling needs.

The ServiceContractUse extends the UML CollaborationUse and explicitly specifies the
use of the interoperation described in a Service Contract.

A RoleBinding binds each of the Roles of a ServiceContract to a Participant, both of which are referenced in an ExtendedIncrementArchitecture.

The attribute architecturalImpact allows developers to specify the architectural change (Add, Modify, and Delete) that an architectural element (i.e., ParticipantUse, RoleBinding, ServiceContractUse) will produce on the current ApplicationArchitectureModel.

Integration Specification

In order to specify increment integration, developers take the input Microservice Architecture Model and create a Participant that becomes its owner, and the Microservice Architecture Model input then becomes the Services Architecture of the Participant created. As stated previously, the Services Architecture of the participant not only describes the inner architectural elements of the microservice, but also its interoperation requirements, which describe the outside roles that external Participants must play in order to interact with the microservice along with interaction among those roles by means of the outside ServiceContracts also described.

Once the Participant representing the microservice to be integrated has been created, developers specify integration logic by creating an ExtendedIncrementArchitecture element, and then create its inner parts: i) a ParticipantUse that references the already created Participant; ii) ParticipantUses that reference Participants belongings to the current Application Architecture Model that will play the outside roles, and with which the microservice(s) to be integrated will interoperate; iii) ServiceContractUses that specify interoperation among Participants by referencing the aforementioned outsideServiceContracts; iv) RoleBindings that bind each of the roles defined in an outsideServiceContract to the ParticipantUse that will play the role.

Developers specify the architectural impact of integration by tagging ExtendedIncrementArchitecture inner parts with architecturalImpact values that describe how they collaborate to reconfigure the Application Architecture Model (e.g., by adding RoleBindings, adding Participants, removing Participants). Finally, developers specify information about the management of changes in workload required by each ParticipantUse and ServiceContractUse by specifying elasticityLevel and delayLevel values.

By creating Extended Increment Architecture Models, which extend UML and SoaML, developers satisfy Componentization via Services and Organized Around Business Capabilities principles. Furthermore, having Microservice Architecture Models as input allow developers to take full responsibility for the software in production, which facilitates incremental integration and satisfies the Evolutionary Design and Products not Projects principles. Designing microservice integration in advance simultaneously gives different development teams working on different microservices the independence to design, implement and deploy microservices.

Increment Implementation

This activity aims to support the integration process by generating platform-specific cloud artifacts (software artifacts to be deployed on a cloud platform), includes the following steps:

Check Increment Compatibility

Developers participate in verifying whether the ExtendedIncrementArchitectureModel is compatible with the current ApplicationArchitectureModel. If discrepancies exist between the Participant’s interfaces (e.g., different names for methods and services, different message ordering), they design a ServiceContract that overrides outside ServiceContracts and apply model-to-text (M2T) transformations that generate skeletons of Cloud Adaptors (see Fig.1).

Specify the Packaging and Deployment Structure

In this step, developers apply model-to-model (M2M) transformations to translate the Extended Increment Architecture Model into a model that describes the cloud artifacts needed to implement its inner parts (DIARyArchitecturalElement), the Increment Cloud Artifacts Model
This model organizes cloud artifacts into projects that can be packed/built/deployed independently in different cloud environments in accordance with decisions made during the development process (e.g. technology, microservice workload management decisions). This model promotes the decoupling of software artifacts that implement interaction protocol from those that implement microservice design, thus satisfying the Smart Endpoints and Dumb Pipes microservice principles. The Increment Cloud Artifacts Model complies with the Cloud Artifacts Model meta-model (see Fig.3).

Fig. 3. Extract of Cloud Artifacts Model meta-model

The Cloud Artifacts Model meta-model

The way in which microservices are deployed has an influence on satisfying SLA terms or other nonfunctional requirements [7] (e.g., agility to deploy, modifiability, monitoring, cost of provisioning). We use Projects to manage the building, packaging and deployment options. M2M transformation rules map Interaction Projects onto Service Contracts (see Fig.2) architectural elements, and generate descriptions of cloud artifacts that allow developers to implement interoperation among microservices as a separate service. An Interaction Project includes the following cloud artifacts: Interaction Service Hosted Services that implement interoperation interaction protocols, Interface definitions, and Service data (message Types or data Types). M2M transformation rules map inner parts of Service Contracts architectural elements onto these cloud artifacts.

Implementation Projects, in the case of Participants that provide services, are mapped onto Service Architectures of the participant architectural elements (see Fig.2). These Implementation Projects include descriptions of Artifacts, such as FrontEndService Hosted Services that implement microservice business logic, Interface implementations of interfaces defined in related Service Contracts, or backend HostedServices that use cloud environment services (e.g., message queues). In the case of Participants that consume services, Implementation Projects are mapped onto related ServiceContracts in order to describe ClientObjectArtifacts that implement related Interfaces and initiate the service execution by invoking InteractionServices or Adaptors that correct incompatibilities between interfaces. For detailed mappings see [23].

Deployment Projects and Interaction/Implementation Projects facilitate the packaging of Artifacts into a deployable package. Microservices whose related projects are included in a Deployment Project will be implemented with the same technology and deployed in the same cloud environment, whereas Artifacts included in an Interaction/Implementation project will be packed together in the same deployment artifact and deployed in the same cloud environment resource (e.g., virtual machine), thus sharing cloud environment resources. Including
microservice related *Artifacts* in an exclusive or shared *Interaction/Implementation Project* allows developers to manage workload changes and running costs.

*DynamicConfiguration* classes describe configuration *Settings* (e.g., Provisioning Configurations) that could change at runtime. *Settings* and Invoked/Exposed *EndPoints* information will therefore be stored outside the deployable package. Thus enabling them to be updated without requiring the redeployment of the entire package, a best practice in the CD [15].

In order to *Specify the Packaging and Deployment Structure*, we provide an Eclipse plug-in which executes M2M transformations carried out using the Atlas Transformation Language (ATL) to generate *Increment Cloud Artifacts Models* from *Extended Increment Architecture Models*. Input/Output models are implemented as ecore models in the Eclipse Modeling Framework (EMF). Transformations generate descriptions of the cloud *Artifacts* required to implement architectural elements and define the packaging/deployment structure by assigning *Artifacts* to different *Interaction/Implementation/Deployment Projects* according to the *architecturalImpact*, *delayLevel* and *elasticityLevel* values. Fig. 4 (lines 3, 6, 10) shows an example of the transformation rule applied to assign the *Artifacts* corresponding to *Participants* (e.g., microservices) that require a high *elasticityLevel* into an exclusive *ImplementationProject* (e.g., an exclusive virtual machine) that is assigned to a *DeploymentProject* (e.g., cloud platform).

**Generate Implementation Code**

In this step, cloud developers make decisions regarding implementation and deployment technologies that best fit the individual requirements of each microservice included in an increment, and then complete the previously generated *Increment Cloud Artifacts Model* by specifying: i) the technology in which each artifact included in a *DeploymentProject* will be implemented and deployed; ii) provisioning, deployment, and inter-service communication information for each *Implementation/InteractionProject*, along with microservice configuration information for each *HostedService*, by creating or updating classes of the *DynamicConfiguration*, *Setting* type (e.g., number of service instances, memory, credentials), or *EndPoint* (e.g., SOAP/REST service style, message format, protocols); iii) the *representation* of each Artifact (e.g., source code language); iv) the *location* of artifacts to be generated.

Next developers execute M2T transformations that use this model and the *Extended Increment Architecture Model* as input in order to generate the cloud artifact implementations, which are organized into a directory structure according to the *Location* specified for each *Project*. The cloud artifacts generated implement (see Fig. 1): i) an *Interaction Protocol*, ii) software *Cloud Adaptors*, iii) *Cloud Artifacts* that implement microservice logic, APIs that microservices expose, and as many configuration files as *DynamicConfigurationEnvironments* (e.g., development, production), iv) *Building Scripts/Packaging Scripts* to create deployable packages, according to the *DeploymentProjects’* structure. Finally, cloud developers complete the cloud artifacts generated and execute packaging and building scripts to obtain deployable packages.

<table>
<thead>
<tr>
<th>Rule</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>01.</td>
<td>Create a implementation project (and related elements) per ParticipantUse</td>
</tr>
<tr>
<td>02.</td>
<td>from</td>
</tr>
<tr>
<td>03.</td>
<td>ParticipantInput : eiam!ParticipantUse(</td>
</tr>
<tr>
<td>04.</td>
<td>ParticipantInput.elasticityLevel = 4 )</td>
</tr>
<tr>
<td>05.</td>
<td>to</td>
</tr>
<tr>
<td>06.</td>
<td>implementation : cam!ImplementationProject(</td>
</tr>
<tr>
<td>07.</td>
<td>name &lt;- ParticipantInput.name,</td>
</tr>
<tr>
<td>08.</td>
<td>belongsToParticipant &lt;- ParticipantInput.participantType,</td>
</tr>
<tr>
<td>09.</td>
<td>artifacts &lt;- front,</td>
</tr>
<tr>
<td>10.</td>
<td>deployment &lt;- thisModule.resolveTemp(</td>
</tr>
<tr>
<td>11.</td>
<td>ParticipantInput.participantType, 'DeploymentProject')),</td>
</tr>
<tr>
<td>12.</td>
<td>front : cam!FrontEndService(</td>
</tr>
<tr>
<td>13.</td>
<td>serviceProject &lt;- implementation),</td>
</tr>
<tr>
<td>14.</td>
<td>configImplement : cam!DynamicConfiguration(</td>
</tr>
<tr>
<td></td>
<td>Create a DynamicConfiguration element</td>
</tr>
</tbody>
</table>
Deployment & Architectural Reconfiguration

In this activity developers select the adaptation patterns best suited to integrating the increment’s architecture into the current application architecture and execute M2T transformations that generate cloud artifacts that operationalize the adaptation patterns according to Extended Increment Architecture Model and the Increment Cloud Artifacts Model. The cloud artifacts generated are (see Fig.1): i) Deployment Scripts with which to deploy (and provision) previously generated packages along with the corresponding configuration files, and ii) scripts with which to reconfigure the application architecture, which use architectural impact specification to dynamically update EndPoints information stored in the microservice configuration files. Finally, the Extended Increment Architecture Model and the Increment Cloud Artifacts Model are used as the input for the M2M transformations that update both the current Application Architecture Model and the Application Cloud Artifacts Model by integrating the corresponding architectural elements and cloud artifact descriptions (see Fig.1).

The Increment Implementation and Deploy & Architectural Reconfiguration activities allow developers to satisfy the Decentralized governance and Infrastructure Automation microservice principles by providing models that abstract implementation and deployment decisions from technological aspects, and tools that enable developers to obtain software artifacts that can be used as part of CI/CD pipelines.

4. Case Study

In order to illustrate the use of our approach, in this section we present an excerpt of a case study (adapted and extended from [3]). A manufacturing company wishes to improve the technological support given to its dealers, and is considering updating its already existing manufacturer microservice by including new functionalities with which to allow dealers to place production orders and obtain the products ordered by means of a shipping service. Fig. 5a shows an extract of the current Application Architecture Model which will be involved after integrating the Manufacturer’s microservice update.

The development team involved in this new requirement used SoaML to model the architectural design of the new manufacturer microservice functionalities and produce the Microservice Architecture Model (Fig. 5b), described as a Services Architecture, whose inner parts (e.g., ServiceContracts, Interfaces, Roles) are not shown owing to space restrictions. The Microservice Architecture Model includes microservice architectural elements that describe microservice logic and architectural elements that describe microservice interoperation requirements (depicted with a background color in Fig. 5b). Note that the Participants that are expected to interoperate with the manufacturer microservice (other components/microservices that consume manufacturer microservice’s services or provide it with services) are indicated by the ParticipantUses with dashed outlines (i.e., :Dealer and :Shipper), whereas that internal microservice components are normal ParticipantUses.

Fig. 6a shows the Extended Increment Architecture Model resulting from the Increment Integration Specification activity, in which the Microservice Architecture Model (Fig. 5b) becomes the Service Architecture of the participant Manufacturer, which is referenced by the manufacturer ParticipantUse architectural element. The Microservice interoperation requirements described in the Microservice Architecture Model (depicted with a background color in Fig. 5b), was referenced in the Extended Increment Architecture Model, thus becoming the microservice integration logic (depicted with a background color in Fig. 6a).
Developers proceed to specify the Participants that will play the roles defined in the integration logic. The Participant Manufacturer already exists in the Current Architecture Model, and the manufacturer ParticipantUse is therefore tagged with architecturalImpact = Modify. The Dealer and Shipper Participants do not exist in the Current Architecture Model and must therefore be created, which is specified by tagging the ParticipantUses with architecturalImpact = Add. Finally, the requirements for workload change management are specified; in this case study, the new Manufacturer functionalities require a High ElasticityLevel that differs from the current requirements (see Fig. 5a).

During the Increment Implementation activity there were no inconsistencies among Participants’ interfaces, and the interaction protocols described in the interaction logic were not therefore changed. The Increment Artifacts Model (Fig. 6b) was generated by applying M2M transformations of the Eclipse plug-in provided with this method, and it was then completed. As the M2T transformations that generate Implementation Code (Fig. 6c) are not yet finished, we therefore implemented the cloud artifacts required manually, built the application, packed it and deployed it in the Microsoft Azure cloud environment.

During the Deployment & Architectural Reconfiguration, we use the open source Eclipse...
extension Acceleo M2T generator in order to obtain Reconfiguration Scripts (see Fig. 6c). We generated XML Document Transform (XDT) files used in Visual Studio to modify service configuration files while the deployment takes place. Fig.7 (lines 12, 13, 14) shows an example of the transformation rule applied to modify configuration information related to bindings among services in accordance with architectural impact specification.

Finally, the M2M transformations that update current application models (see Fig. 6c) are in the process of being built; however Fig. 8 shows how the Application Model Architecture is expected to look after integration.

5. Conclusions and Future Work

We presented a general view of a method for the incremental integration of microservices into cloud applications. In this method, developers specify how to integrate a microservice into the current application by describing both the integration logic and the architectural impact of integration without taking into consideration the specifics of any cloud environment. They then use both the microservice design and the integration specification to generate: i) skeletons of the microservice implementation code and the integration logic implementation code, ii) scripts to build and package the related microservice software artifacts, iii) scripts to deploy the microservices, and iv) scripts to manage the current application’s architectural reconfiguration produced by the integration. Particular emphasis has been placed on explaining how the method manages to keep the microservice design independent from the integration specification, thus allowing different development teams to work on different microservices and giving them the independence to design, implement and deploy microservices according to the implementation/deployment technological requirements of each microservice. Providing developers with tools that automate integration and deployment operations help developers in eliminating discontinuities between development and deployment through CI/CD support which is required in order to deliver new functionalities to customers in an agile manner.

We have shown the feasibility of our proposal by applying it to a case study. We are currently working on implementing transformation chains; however, our approach does not take into account the automation of infrastructure changes. We are considering the use of the DevOps approach in order to improve the collaboration between development and operations, thus allowing new software releases to be made available much faster [22]. In this context, as further work we plan to adapt the method presented in this work in order to satisfy DevOps practices which promote the automation of the process of software delivery and infrastructure
changes. Additionally, even though microservices related artifacts are generated according to architectural impact of microservices’ versions, we plan to provide mechanisms to manage incremental consistency, avoiding to lose changes introduced in the implementation code after generation (e.g., changes in interface implementations). Finally, we also plan to design experiments with which to validate the effectiveness of our approach in practice.

Acknowledgements

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