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Diplomarbeit Nr. 3616

**Bootstrapping
Provisioning Engines for
On-demand Provisioning
in Cloud Environments**

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begonnen am: 08.01.2014

beendet am: ???.???.2014

CR-Klassifikation: C.2.4, D.2.2, D.2.13, H.4.1, I.6.7

Abstract

The assumption that services should run continuously is no longer reasonable in science oriented environments, where dynamic working approaches lead to fluctuating service utilization. For on-demand provisioning of services in cloud environments, suitable provisioning engines have to be set up first. This diploma thesis presents the design for a 2-tiered bootware component that deploys provisioning engines into remote environments that can then be used to provision services on-demand. The bootware can be called by other components via a web service interface and supports multiple provisioning engines and cloud environment via plugins. The integration of the bootware into the SimTech SWfMS with an Eclipse plugin is also described, the bootware however is designed a generic component that can be used together with other systems.

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List of Abbreviations

| | |
|---------|---|
| AMI | Amazon Machine Image, page 13 |
| APIs | application programming interfaces, page 14 |
| APT | Advanced Packaging Tool, page 30 |
| AWS | Amazon Web Services, page 16 |
| BPEL | Business Process Execution Language, page 13 |
| BPMN | Business Process Modeling Notation, page 13 |
| CLI | command-line interface, page 67 |
| CORBA | Common Object Request Broker Architecture, page 42 |
| CSAR | Cloud Service Archive, page 14 |
| EC2 | Elastic Compute Cloud, page 16 |
| FSM | Finite State Machine, page 66 |
| IaaS | Infrastructure as a Service, page 15 |
| JPF | Java Plugin Framework, page 83 |
| JRE | Java Runtime Environment, page 82 |
| JSPF | Java Simple Plugin Framework, page 83 |
| NIST | National Institute of Standards and Technology, page 15 |
| OASIS | Organization for the Advancement of Structured Information Standards, page 12 |
| ODE-PGF | ODE Pluggable Framework, page 22 |
| OMG | Object Management Group, page 42 |
| OS | Operating System, page 15 |

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| OSGi | Open Service Gateway initiative, page 83 |
| PaaS | Platform as a Service, page 15 |
| PCI | Payment Card Industry, page 20 |
| PubSub | publish-subscribe pattern, page 53 |
| RDC | Remote Desktop Connection, page 30 |
| REST | Representational State Transfer, page 42 |
| RMI | Remote Method Invocation, page 41 |
| SaaS | Software as a Service, page 15 |
| SCXML | State Chart XML, page 87 |
| SDKs | Software Development Kits, page 17 |
| SIMPL | Simulation Data Management System, page 22 |
| SimTech | Simulation Technology, page 21 |
| SimTech Modeler | SimTech Workflow Modeling & Monitoring Tool, page 22 |
| SLA | Service Level Agreement, page 15 |
| SMC | State Machine Compiler, page 87 |
| SOA | Service Oriented Architecture, page 18 |
| SOAP | Simple Object Access Protocol, page 42 |
| SPI | Service Provider Interface, page 82 |
| SSH | Secure Shell, page 11 |
| SWfMSs | scientific workflow management systems, page 21 |
| TOSCA | Topology and Orchestration Specification for Cloud Applications, page 12 |
| UDDI | Universal Description, Discovery, and Integration, page 19 |
| VMs | virtual machines, page 10 |
| VNC | Virtual Network Computing, page 30 |
| W3C | World Wide Web Consortium, page 87 |
| WSDL | Web Service Description Language, page 19 |

1 Introduction

Workflow technology and the service based computing paradigm were mostly used in a business context until now. But slowly they are extended to be used in other fields, such as eScience, where business centric assumptions that were previously true aren't reasonable anymore. One of these assumptions is that services should run continuously. This made sense in large enterprises where those services are used often. Science, on the other hand, often takes a more dynamic approach, where certain services, for example for simulation purposes, are only used at certain times. In those cases, it would make more sense to dynamically provision services only when they are needed.

1.1 Task of this Diploma Thesis

The task of this diploma thesis is to design a small, independent bootstrapping system that can, automatically and on-demand, deploy provisioning engines in cloud environments. It should be able to provision various provisioning engines in different cloud environments. The provisioning engines then handle the actual provisioning of required workflow systems and services. A managing component that keeps track of provisioned environments is also part of this system. Support for different cloud environments and provisioning engines should be achieved through means of software engineering. A functioning prototype that supports Amazon¹ as cloud environment and OpenTOSCA² as provisioning engine should be implemented.

1.2 Structure of this Document

We begin with an introduction to some fundamental topics in Chapter 2. First, we explain bootstrapping, followed by a general overview of provisioning with some details on TOSCA

¹<http://aws.amazon.com/>

²<http://www.iaas.uni-stuttgart.de/OpenTOSCA/indexE.php>

and OpenTOSCA. We explain the concept of cloud computing and describe Amazon's cloud platform. We also present the basics of service oriented architecture, workflows, and workflow management systems. Finally, we describe the SimTech project as well as the SimTech SWfMS.

In Chapter 3 we present previous work on the subject of this diploma thesis. First, we summarize the paper that build the foundation of this diploma thesis. Then, we discuss a previous diploma thesis that extended parts of this paper. In Chapter 4 we also present some related work. We list the requirements that were given for this diploma thesis in Chapter 5. We also explain some additional constraints that we introduced.

We present the design of the bootware in Chapter 6. First, we discuss component division, followed by the integration into existing modeler applications. Next, we select an external communication mechanism. We describe the extensibility mechanism, followed by the different kinds of plugins. We also discuss internal communication, the context object, the web service interface, and the instance store. Then, we describe the execution flow and the use of finite state machines, before the final bootware architecture is presented. We also present a step by step description of the whole bootstrapping process in Chapter 7.

In Chapter 8 we present details on the implementation of the bootware. We describe the integration into the SimTech Modeler with an Eclipse plugin. We also explain the bootware core library. Then, we select the plugin framework, PubSub library, and state machine library that we will use for the implementation. We also describe the context object and the web service operation. Then, we give an overview over some plugins we implemented. In Chapter 9 we list some possibilities for future improvement. We summarize the previous chapters in Chapter 10, before presenting a conclusion.

2 Fundamentals

This chapter starts with a short description of bootstrapping, followed by an introduction into provisioning. Then, we provide a short overview of the cloud landscape, with focus on Amazon's cloud offerings, since these are used in this diploma thesis. We also introduce service oriented architecture and explain workflows and workflow management systems. We finish with an overview of the SimTech project¹, of which this diploma thesis is a part of.

2.1 Bootstrapping

The term *to bootstrap sth.* appears to have originated in the early 19th century in the United States, where phrases like "pulling oneself up over a fence by the straps of one's boots" were used as a figure for an impossible task [40]. In the early 20th century the metaphor's sense shifted to suggest a possible task, where one improves one's situation by one's own efforts without help from others. An example of this can be found in James Joyce's Ulysses from 1922, where he writes about "others who had forced their way to the top from the lowest rung by the aid of their bootstraps" [19]. From there, the metaphor extended to the general meaning it has today which is the act of starting a self-sustaining process that proceeds without help from the outside.

An early reference to bootstrapping in the context of computing dates back to 1953, describing the bootstrapping technique as follows: "Pushing the load button then causes one full word to be loaded into a memory address [...], after which the program control is directed to that memory address and the computer starts automatically. [This] full word may, however, consist of two instructions of which one is a Copy instruction which can pull another full word [...], so that one can rapidly build up a program loop which is capable of loading the actual operating program" [8].

The term bootstrapping is also used with a similar meaning in a business context, where it refers to the process of starting and sustaining a company without outside funding. The

¹<http://www.iaas.uni-stuttgart.de/forschung/projects/simtech/>

company is started with money from the founders, which is used to develop a product that can be sold to customers. Once the business reaches profitability it is self-sufficient and can use the profits it generates to organically grow further [26].

In this diploma thesis, bootstrapping describes the process of starting a simple program that without further help is able to start much more complex programs. These complex programs might require additional middleware, databases, or other components. During the bootstrapping process, all these dependencies will be set up automatically.

2.2 Provisioning

This section provides an overview of provisioning in the context of computing. First, we present a general introduction and describe some of the provisioning solutions available today. Then, we focus in particular on TOSCA and OpenTOSCA, since those are used in the prototypical implementation later on.

2.2.1 Overview

Setting up a complex distributed system with many different components scattered across multiple environments is a time-consuming task if done by hand. For this reason, many provisioning solutions have been created over the years to automate this process. They differ in some areas that we will discuss later, but their core functionality is basically identical: They prepare all necessary resources for a certain task. This core functionality can be stated more precisely with the following definition: Provisioning is, “in telecommunications, the setting in place and configuring of the hardware and software required to activate a telecommunications service for a customer; in many cases the hardware and software may already be in place and provisioning entails only configuration tasks” [12]. Since we are working in a cloud environment, we won’t have to deal with hardware directly, but rather with virtual machines (VMs). So for us, provisioning means the creation and deletion of VMs in a cloud environment, as well as the installation, configuration, monitoring, running and stopping of software on these VMs [20].

There are many benefits to using an automated provisioning solution instead of doing the provisioning by hand. The manual approach is limited by how much work a single person can do at any time, whereas an automatic approach is able to do much more work, in less time, and potentially in parallel. This makes it possible to manage huge infrastructures with very

little resources, which can save money compared to a manual approach. Since every step that needs to be done to provision a system has to be written down, a detailed description of the whole provisioning process is created. This makes the whole process reproducible and less error-prone, since the human factor is largely replaced by automation. Parts of such a description can also be shared in a business or even between businesses, which makes the process of creating such a description potentially much more efficient.

The general process of working with provisioning software is very similar with all the different solutions. It can be described as a two step process. In step one, a description of the whole provisioning process has to be created using the tools provided by the particular solution. In general this involves creating a textual description in a certain format that is understood by the provisioning software that is to be used. In this description, we tell the software what virtual resources we need, what software should be installed on them and how everything should be configured. In step two, we pass this description to the provisioning software, which interprets and executes it.

Many different provisioning solutions exist today. Some cloud providers offer provisioning solutions that are particularly tailored to their cloud offerings, for example AWS CloudFormation², which can only be used to provision resources in the Amazon cloud. Then, there are more generally usable provisioning solutions that are not bound to any particular cloud provider. A few popular examples include Ansible³, Chef⁴, Puppet⁵, and TOSCA⁶, which we will discuss in detail later.

All these solutions differ in some form or another. A full feature comparison of different solutions is out of scope for this diploma thesis, but what follows is a short overview of some of the differences. As already mentioned, AWS CloudFormation is bound to Amazons cloud platform, while the other solutions are not. Chef and Puppet both use a client server architecture, where each node that should be configured by them has to run a client program to communicate with a server node, whereas Ansible executes its command over Secure Shell (SSH) and therefor doesn't require additional software on the nodes that are configured. The solutions also differ in modularity and flexibility. While Ansible, Chef, Puppet, and TOSCA are highly flexible and can be used in a fine grained modular fashion, this also makes them more complex to use, for example compared to AWS CloudFormation.

²<http://aws.amazon.com/cloudformation>

³<http://www.ansible.com>

⁴<http://www.getchef.com/chef>

⁵<http://puppetlabs.com/>

⁶https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=tosca

2.2.2 TOSCA

Topology and Orchestration Specification for Cloud Applications (TOSCA) is a standard created by the Organization for the Advancement of Structured Information Standards (OASIS)⁷. Its development is also supported by various industry partners, which include IBM, Cisco, SAP, HP and others. Its aim is to provide a language that can describe service components and their relations in a cloud environment independent fashion. The following description is based on version 1.0 of the specification [32].

TOSCA defines an XML syntax, which describes services and their relations in a so called service template. All elements needed to define such a service template are provided in the TOSCA definitions document. Figure 2.1 shows such a definitions document. Aside from the actual service template, shown on the left, it also contains a number of type definitions and some templates based on those definitions. These definitions and templates can also be imported from a separate definitions document.

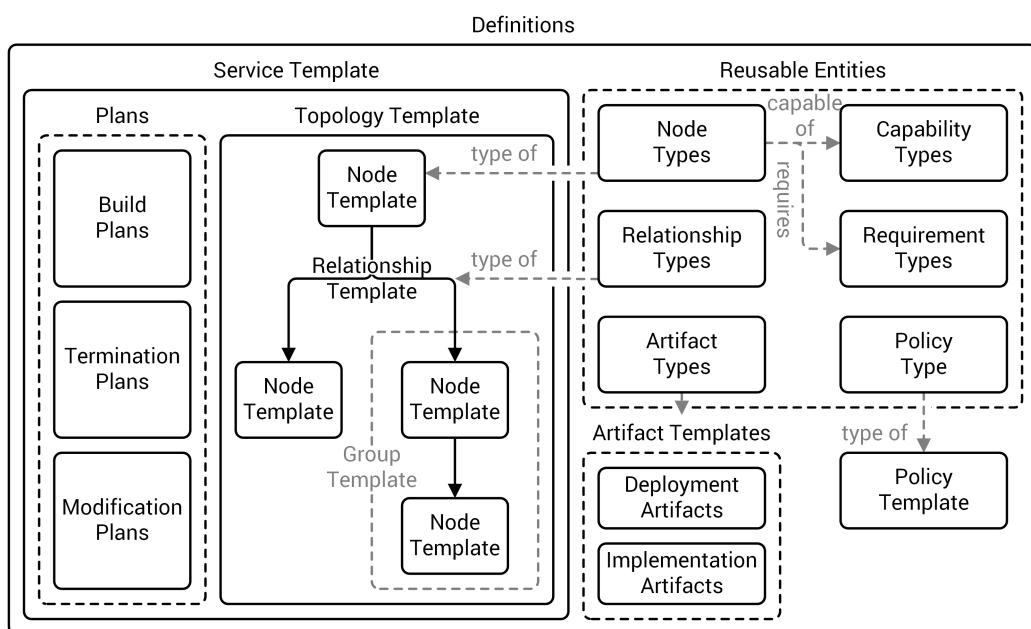


Figure 2.1: TOSCA definitions structure [based on 32].

The service template consists of two parts: A topology template and plans. Topology templates, as seen in the center of Figure 2.1, model the structure of a service and the middleware and infrastructure supporting it as a directed graph. The vertices of the graph represent

⁷<https://www.oasis-open.org/>

nodes which are occurrences of a specific component, for example, an application server or a database. These nodes are defined by node types or by other service templates. Node types are reusable entities, as shown in the top right of Figure 2.1. They define the properties of a component, as well as operations to manipulate a component, so called interfaces. Additionally, node types can be annotated with requirements and capabilities. These, in turn, are defined by requirement and capability types, which also belong to the group of reusable entities. This allows for requirement and capability matching between different components. The edges of the graph represent connections between nodes, which are defined by relationship templates that specify the properties of the relation. An example for such a connection would be a node A, representing a web service that is deployed on node B, an application server. Relationship types are also used to connect requirements and capabilities.

Plans, shown on the left of Figure 2.1, are used to manage the service that is defined by the service template. TOSCA distinguishes between three types of plans: Build plans, termination plans, and modification plans. Build plans describe how instances of a service are created. Termination plans describe how such a service is removed. Modification plans manage a service during its runtime. These plans consist of one or more tasks, i.e., an operation on a node (via an interface) or an external service call, and the order in which these tasks should be performed. They can be written in a process description language like Business Process Execution Language (BPEL)⁸ or Business Process Modeling Notation (BPMN)⁹.

The bottom right of Figure 2.1 shows artifact templates which represent artifacts. Artifacts are things that can be executed directly (e.g.: scripts, archives) or indirectly (e.g.: URL, ports). TOSCA further distinguishes between two types of artifacts, namely deployment and implementation artifacts. Deployment artifacts materialize instances of a node and are used by a build plan to create a service. An example for this is an Amazon Machine Image (AMI) which creates an Apache server once deployed in a VM. Implementation artifacts implement the interfaces of components. Here, an example would be a node that has an interface for starting the particular component described by the node. This interface could be implemented by an implementation artifact like a *.jar* file.

The bottom right of Figure 2.1 also shows policy templates that refer to specific policy types. A policy template can define concrete values for a policy specified in a policy type. A node template can then reference a policy template to declare that it supports some non-functional properties or a certain kind of quality-of-service. An example would be a node type for an application server that expresses that it supports high availability by referencing a matching policy template.

⁸<http://docs.oasis-open.org/wsbpel/2.0/OS/wsbpel-v2.0-OS.html>

⁹<http://www.bpmn.org/>

One or more TOSCA definitions are packaged, together with some metadata and possibly other files, into a Cloud Service Archive (CSAR), which is essentially a zip file that contains all files necessary to create and manage a service. CSAR files can then be executed in a TOSCA runtime environment, also called TOSCA container, to create the service described within.

2.2.3 OpenTOSCA

OpenTOSCA is a browser based open-source implementation of a TOSCA container, created at the IAAS at University Stuttgart, which supports the execution of TOSCA CSAR archives [2]. Figure 2.2 shows the architecture of OpenTOSCA. Its functionality is realized in three main components, which are the Controller, the Implementation Artifact Engine, and the Plan Engine. After a CSAR is uploaded to OpenTOSCA it can be deployed in three steps. In the first step, the CSAR file is unpacked and its content is stored for further use. The TOSCA XML files are then loaded and processed by the Controller. The Controller in turn calls the Implementation Artifact Engine and the Plan Engine. The Implementation Artifact Engine knows how to deploy and store the provided implementation artifacts via plugins. Plans are then run by the Plan Engine, which also uses plugins to support different plan formats. OpenTOSCA also offers two application programming interfaces (APIs), the Container API and the Plan Portability API. The Container API can be used to access the functionality provided by the container from outside and to provide additional interfaces to the container, like the already existing admin UI, self-service portal, or modeling tool. The Plan Portability API is used by plans to access topology and instance information [2].

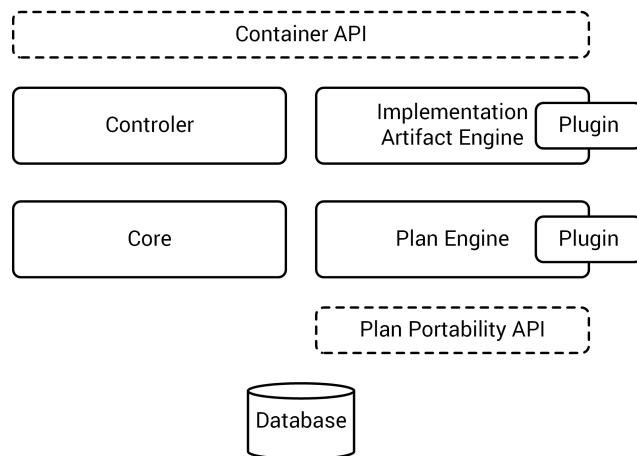


Figure 2.2: OpenTOSCA architecture [based on 2].

2.3 Cloud Computing

Cloud computing emerged in recent years as an alternative to traditional IT. Compared to traditional IT, it offers customers far more flexibility in terms of short term access to and scalability of resources, such as servers, databases, communication services, etc. This increased flexibility is the result of a combination of certain technologies and business models that, although having been around for a while individually, were combined only in recent years. Since cloud computing is a relatively new phenomenon, there are many definitions of it scattered around. Vaquero et al. looked at over 20 of them and proposed the following definition:

"Clouds are a large pool of easily usable and accessible virtualized resources (such as hardware, development platforms and/or services). These resources can be dynamically reconfigured to adjust to a variable load (scale), allowing also for an optimum resource utilization. This pool of resources is typically exploited by a pay-per-use model in which guarantees are offered by the Infrastructure Provider by means of customized SLAs."¹⁰ [33]

The National Institute of Standards and Technology (NIST) also proposes a definition:

"Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." [22]

Cloud services can be categorized into different cloud service models, according to what exactly each service encompasses [25]. Figure 2.3 shows the three most common service models. Infrastructure as a Service (IaaS) is at the lowest level and provides a customer with access to a virtualization environment on top of servers, storage, and networking. Here, the customer has to manage the Operating System (OS), middleware stack, applications, and data him self. Platform as a Service (PaaS) is the next higher tier, which offers a customer access to a fully managed runtime environment in the cloud. Here, the customer only has to manage the application they want to execute in the runtime environment and the data. Finally, Software as a Service (SaaS) offers a customer access to a fully managed application running in the cloud. In this case, the user has to manage neither the OS, nor any middleware, application, or data.

¹⁰Service Level Agreement (SLA): "An agreement that sets the expectations between the service provider and the customer and describes the products or services to be delivered, the single point of contact for end-user problems and the metrics by which the effectiveness of the process is monitored and approved." [30]

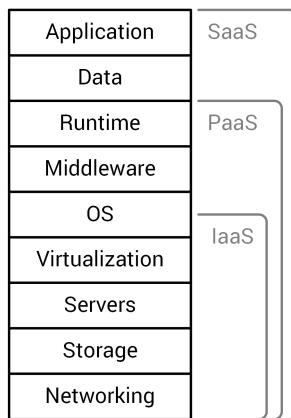


Figure 2.3: Cloud service models [based on 15].

Today, there are many different cloud providers offering a huge selection of services. The range of providers spans from large corporations like Amazon¹¹, Google¹², Microsoft¹³, and IBM¹⁴ to small, focused providers like Heroku¹⁵ or Jelastic¹⁶ and even solutions to build own clouds, like OpenStack¹⁷. The next section describes Amazon's cloud services in more detail, since those will be used in this diploma thesis.

2.3.1 Amazon Web Services

In 2006, Amazon started offering cloud resource under the umbrella of Amazon Web Services (AWS)¹¹. Since then, their offerings steadily increased and do now comprise over 20 different products and services for computing, data storage, content delivery, analytics, deployment, management, and payment in the cloud.

The most relevant cloud offering for this thesis is Elastic Compute Cloud (EC2)¹⁸, Amazons IaaS offer. It allows customers to rent virtual server instances at an hourly rate. These servers are freely configurable, so virtually any software can be installed, making EC2 very versatile. In addition to general purpose instances (M3), Amazon offers a wide selection of

¹¹<http://aws.amazon.com>

¹²<https://cloud.google.com>

¹³<http://azure.microsoft.com>

¹⁴<http://www.ibm.com/cloud-computing>

¹⁵<https://www.heroku.com>

¹⁶<http://jelastic.com>

¹⁷<https://www.openstack.org>

¹⁸<http://aws.amazon.com/ec2>

specialized instances, which are optimized for a specific purpose¹⁹. These include instances optimized for computation performance (C3), memory-intensive applications (R3), or high storage instances (I2). For this thesis we will be using Amazons low cost micro instances (T1).

Also of interest to this thesis is Elastic Beanstalk²⁰, Amazons PaaS offering. Customers can upload an application and Elastic Beanstalk takes care of deployment and scaling. This makes it easier and quicker to use than EC2, but also less flexible. It could be used instead of a more manual approach with EC2.

Amazon offers multiple ways to interact with cloud resources. All AWS offerings can be controlled using the AWS Management Console²¹, a web based management interface that allows customers to start, stop, and manage cloud resources on-demand. It also provides access to account and billing information. Additionally, Amazon provides a command line interface, tools for Eclipse and Visual Studio, and Software Development Kits (SDKs) for several programming languages, including Java, .Net, Python, Ruby, and the Android and iOS platforms²². In this thesis, we will use the AWS SDK for Java²³ to interact with Amazons cloud resources programmatically.

2.4 Service Oriented Architecture

In highly dynamic markets, companies must be flexible and adapt their business process quickly to changing environments. This often includes cooperating or merging with other businesses, business process optimization, or outsourcing. There have been distributed system technologies in the past that were created to support such dynamic processes on an IT level, but their tight coupling and lack of interoperability resulted in islands of middleware and corresponding application. The integration between those islands became a new problem that was solved with message oriented middleware [38].

Message oriented middleware enables integration of application by wrapping them in adapters. These adapters are connected with channels which pass along messages. Channels can ensure a certain quality-of-service, such as exactly-once delivery. They also can change the messages in other ways, for example by transforming them between different formats. This allows for loosely coupled communication, since format changes don't affect the ability for two

¹⁹<http://aws.amazon.com/ec2/instance-types/>

²⁰<http://aws.amazon.com/elasticbeanstalk>

²¹<http://docs.aws.amazon.com/awsconsolehelpdocs/latest/gsg/getting-started.html>

²²<https://aws.amazon.com/tools/>

²³<https://aws.amazon.com/sdkforjava>

applications to integrate. The underlying integration middleware can also offer more advanced message exchange patterns, such as asynchronous send and receive or send-and-forget, which further helps with loosely coupled interaction [38].

Service Oriented Architecture (SOA) is an architecture paradigm that emerged as a result from the lessons learned from the failure of other distributed systems and the success of message-oriented middleware. It focuses on loose coupling and dynamic binding between services [38]. In this case, a service is “a logical representation of a repeatable business activity that has a specified outcome” [29]. Further characteristics of services are that they are self-contained, that they are composable, i.e. new services can be build by combining multiple other services, and that they are discoverable based on metadata that describes their various aspects. They also operate like black boxes to their consumers, i.e. no information of how they are implemented or provided is needed to use them [38].

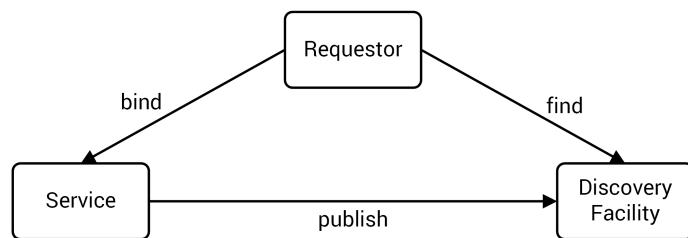


Figure 2.4: The SOA triangle [based on 38].

Figure 2.4 shows the basic principle behind SOA: The SOA triangle, made up of the bind/publish/find approach. First, a provider creates an abstract definition of a service that includes enough information to allow others to bind to this service. The provider then publishes metadata describing this service to a directory or registry. A requestor can then use the discovery facility associated with this registry to find services that fulfills his functional and non-functional requirements, based on the available metadata. After selecting a service, the requestor then retrieves the corresponding binding information, binds to this service and starts sending requests to it [38].

To simplify this process for the requestor, a middleware called service bus is introduced, as shown in the middle of Figure 2.5. The requestor now sends the description of the service it intends to use and the data it intends to send to the service to the service bus. The service bus uses the description to find matching services with the discovery facility, selects one of them, retrieves the binding information and binds to the services. Then, if necessary, it transforms the data send by the requestor and sends a request to the service. The response it receives is passed along to the requestor, who now no longer has to deal with any of the above steps [38].

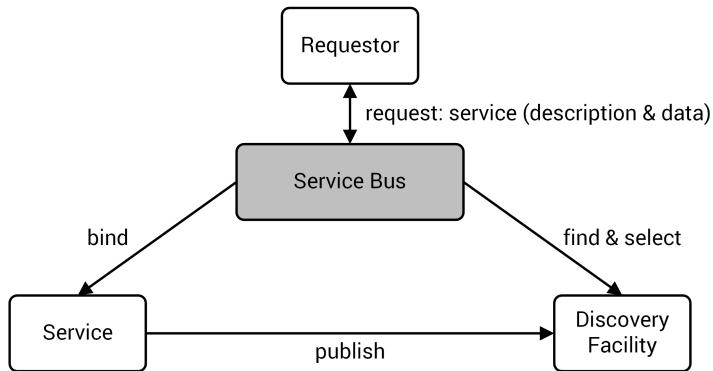


Figure 2.5: The SOA triangle including a service bus [based on 38].

Web service technology is one implementation of a service oriented architecture. It uses wrappers to hide implementation specific functionality and therefore allows applications with different programming models to interact with each other. To describe these wrappers, the standardized Web Service Description Language (WSDL) is used. WSDL describes the interfaces of the wrappers, which allows a requestor to use any wrapper implementing a particular interface, which creates technology abstraction. Additionally, quality-of-service descriptions and business-relevant data allow service selection based on business criteria, rather than IT criteria. This allows requestors to switch dynamically between providers offering identical services with little or no changes to the application, which creates provider abstraction. Universal Description, Discovery, and Integration (UDDI) can be used as a service registry where WSDLs of web services can be published and found [38].

A service bus is also at the center of this implementation. It combines a number of SOA capabilities, specified by numerous web service specifications, to offer the discovery, selection, and binding functionality described earlier. It can cope with various transport protocols and deal with both XML and non-XML messages. Quality of service is supported via policies and can include reliable messaging, security, and transaction capabilities. It also supports atomic services and composed services and provides features for service discovery and negotiation [38].

2.5 Workflows and Workflow Management Systems

Workflows and workflow management systems are another tool to increase the flexibility of businesses in times of change, similar to SOA. Hollingsworth defines a workflow as “the computerised facilitation or automation of a business process, in whole or part” [17]. In other

words, a workflow describes the tasks associated with a business process and the order in which these tasks are to be executed in such a way that they can be automated with the help of computers. Workflows are often visually represented as directed graphs, with vertices representing the tasks and edges defining the order of these tasks. Figure 2.6 such a graph that represents a simple business workflow. Note that the tasks can be a mixture of human and automated tasks. In Figure 2.6 for example, the identify payment method, accept cash, and prepare package tasks could be executed by humans, while the process credit card task would be handled by a computer program. Moreover, in combination with SOA, the process credit card task could be a call to an external service provided by an PCI²⁴ compliant business specialized in payment processing.

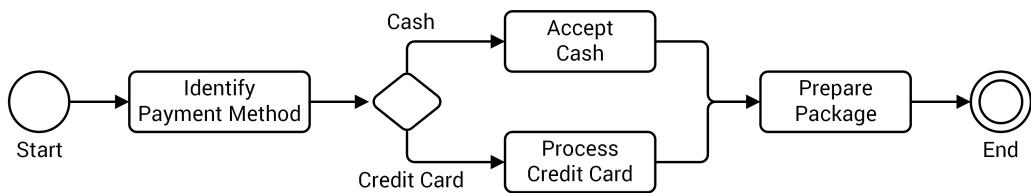


Figure 2.6: A simple workflow represented as a graph.

The automation of a workflow is handled by a workflow management system, which Hollingsworth defines as “a system that completely defines, manages and executes workflows through the execution of software whose order of execution is driven by a computer representation of the workflow logic” [17]. In other words, a workflow management system receives a workflow as input and then executes the actions associated with each workflow task in the particular order described by the workflow. For the example in Figure 2.6, this could mean that the workflow management system presents an employee with a graphical user interface, where they can select the payment method based on the choice of a customer. If the customer chooses to pay cash, the workflow management system would then show a dialog where the employee could enter this cash transaction. If the customer chooses to pay with a credit card, the workflow management system would call an external service with the credit card details to approve the transaction. In the final step, the workflow management system could assist the employee with preparing the package by automatically printing a label or displaying useful information.

In the past, workflows have been mainly applied in a business context, in particular for modeling and re-engineering of business processes. This lead to the development of business-

²⁴Payment Card Industry (PCI): The PCI Security Standards Council developed a data security standard (PCI DSS)²⁵to enhance the security of credit card information. Businesses handling credit card information are encouraged to comply with these requirements to prevent security breaches and improve trust. Since this can be a complicated process, outsourcing credit card handling can save time and effort.

²⁵https://www.pcisecuritystandards.org/documents/PCI_DSS_v3.pdf

centered standards like BPEL or BPMN to describe workflows, and corresponding workflow management system that can execute these workflows. One particular characteristic of these business workflows is that they are fairly static, i.e. they will not change during a workflow execution and only rarely in between due to business process re-engineering. This also means that the existing business workflow infrastructure is geared towards these static workflows [34].

In recent years however, new applications for the use of workflows have emerged, among them scientific workflows. These scientific workflows differ from business workflows in that they are much more dynamic and therefore require more flexibility in the tools supporting them. The reason for this is that the processes involved in scientific workflows are rarely completely known in advance. Exploration and trial and error often play a role, which can lead to unpredictable changes in the processes [34]. Existing workflow technology often can't offer the required flexibility for scientific workflows, which is why modification of existing technology or creation of new technology is required to fully support scientific workflows. Therefore, scientific workflow management systems (SWfMSs) have been created, which offer scientist adequate support throughout the experimentation process.

2.6 SimTech

Since 2005, the German federal and state government have been running the Excellence Initiative²⁶, which aims to promote cutting-edge research, thereby increasing the quality and international competitiveness of German universities. In three rounds of funding, universities have competed with project proposals in three areas: Institutional Strategies, Graduate Schools, and Clusters of Excellence. Simulation Technology (SimTech) is one of the Clusters of Excellence that are funded by the Excellence Initiative. In a partnership between the University of Stuttgart, the German Aerospace Center, the Fraunhofer Institute for Manufacturing Engineering and Automation, and the Max Planck Institute for Intelligent Systems, it combines over 60 projects from researchers in Engineering, Natural Science, and the Life and Social Sciences. The aim of SimTech is to improve existing simulation strategies and to create new simulation solutions [14].

In the SimTech project, seven individual research areas collaborate in seven different project networks, one of which is project network 6: *Cyber Infrastructure and Beyond*. The goal of this project network is to build an easy-to-use infrastructure that supports scientists in their day to day work with simulations [11].

²⁶http://www.dfg.de/en/research_funding/programmes/excellence_initiative/index.html

2.6.1 SimTech SWfMS

As part of this project, the SimTech SWfMS was developed. It is a system that enables scientists to easily create, manage and execute simulation workflows which are a subcategory of scientific workflows [16]. The SimTech SWfMS introduces extensions to the BPEL language that add functionality to support the requirements of simulation workflows, such as passing data by reference to support larger amounts of data often found in science [also see 39], or shared context between workflows [23]. Other extension introduces by the SimTech SWfMS to support simulation workflows include a service bus that supports late binding, rebinding, and legacy simulation software, as well as the Simulation Data Management System (SIMPL) that provides unified access methods for arbitrary external data [27]. Additionally, extension where also made in the areas of flexibility to support a “model as you go” approach and in human user involvement to support human tasks for decision making, data manipulation, or workflow repair [16, 18].

The SimTech SWfMS consists of the SimTech Workflow Modeling & Monitoring Tool (SimTech Modeler) and the workflow middleware. The SimTech Modeler is based on Eclipse JEE²⁷ and extends its functionality with various plugins. Figure 2.7 shows the SimTech Modeler user interface. It allows the user to create simulation workflows using a graph as visual representation, where vertices represent simulation tasks and edges describe the progression between those tasks.

Once the user is done modeling the simulation workflow, they click on a button to execute the workflow on the workflow middleware. The middleware consists of various components, some of which are shown in Figure 2.8. Most of them are executed by an application server, in this case Apache Tomcat²⁸. The workflow is deployed on the workflow engine, in this case ODE Pluggable Framework (ODE-PGF)²⁹, which executes the workflow step by step. If a step involves the execution of a service, the ESB (Apache Service Mix³⁰) is called, who resolves the services and passes along the request and the response. Further components include for example SimTech Auditing, which is used for auditing purposes. It is connected to the workflow engine via a messaging middleware (Apache ActiveMQ³¹). It is also connected to a database where it stores its data.

²⁷<http://www.eclipse.org/ide/>

²⁸<http://tomcat.apache.org/>

²⁹<http://www.iaas.uni-stuttgart.de/forschung/projects/ODE-PGF/>

³⁰<http://servicemix.apache.org/>

³¹<http://activemq.apache.org/>

2 Fundamentals

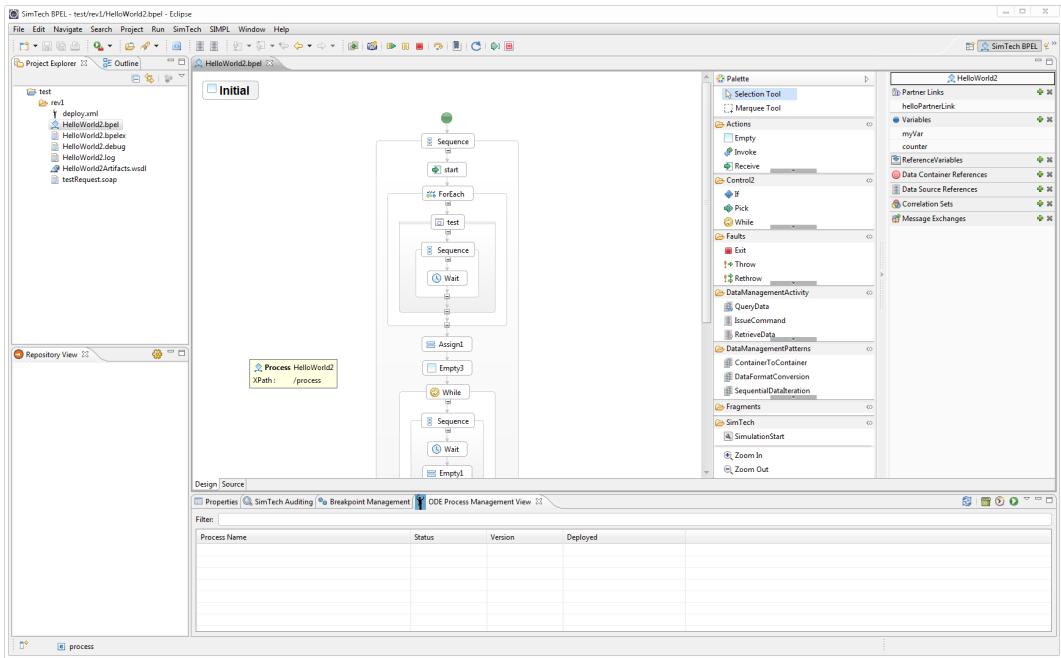


Figure 2.7: The SimTech Modeler user interface.

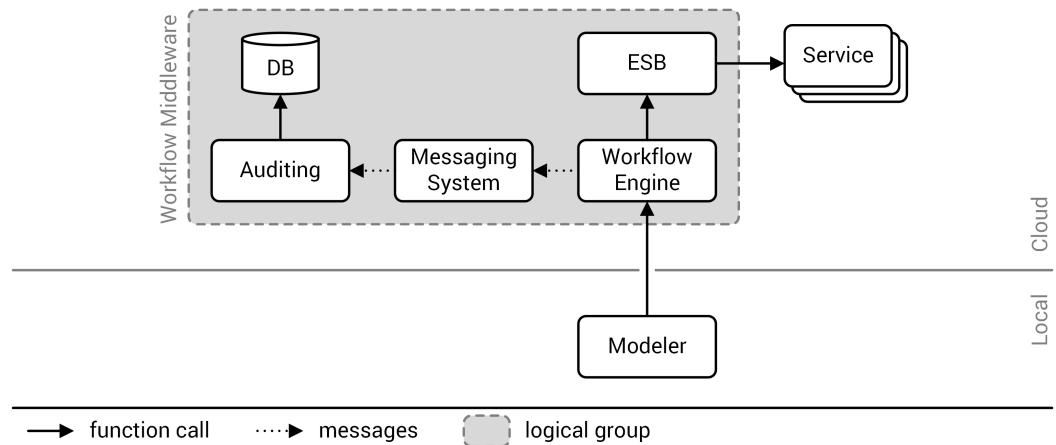


Figure 2.8: Some of the SimTech SWfMS components.

3 Previous Work

This chapter summarizes previous work on the subject of this thesis. First, we present the paper that laid the foundation for this diploma thesis. Then we take a look at another diploma thesis which expanded some ideas presented in the first paper.

3.1 On-demand Provisioning for Simulation Workflows

Vukojevic-Haupt et al. identified requirements that need to be addressed to make the current approach used for scientific workflows more suitable for scientific simulation work [35]. The current approach used in the SimTech SWfMS is based on the assumption of service-oriented computing that services are always running. This can make sense for business applications with a large, steady stream of transactions. Scientific workflows however are executed infrequently, but when they are executed they need a lot of resources. Keeping all those resources running all the time is not efficient, so a more flexible way to allocate and use those resources is needed. The following requirements were identified to be able to improve this situation: Dynamic allocation as well as release of computing resources, on-demand provisioning and deprovisioning of workflow middleware and infrastructure, and dynamic deployment and undeployment of simulation services and their software stacks. To fulfill these requirements, they proposed a new service binding strategy that supports dynamic service deployment, an approach for dynamic provisioning and deprovisioning of workflow middleware, an architecture that is capable of these dynamic deployment and provisioning operations, and, as part of this architecture, the bootware - the subject of this diploma thesis - that kicks off these dynamic processes [35].

The new service binding strategy is necessary, because existing static and dynamic binding strategies, as shown on the left and in the center of Figure 3.1, rely on services that are always running, or, as in the case of dynamic binding with service deployment, only dynamically deploy the service, but not its middleware and infrastructure. The new service binding strategy, shown on the right of Figure 3.1, called *dynamic binding with software stack provisioning*, is

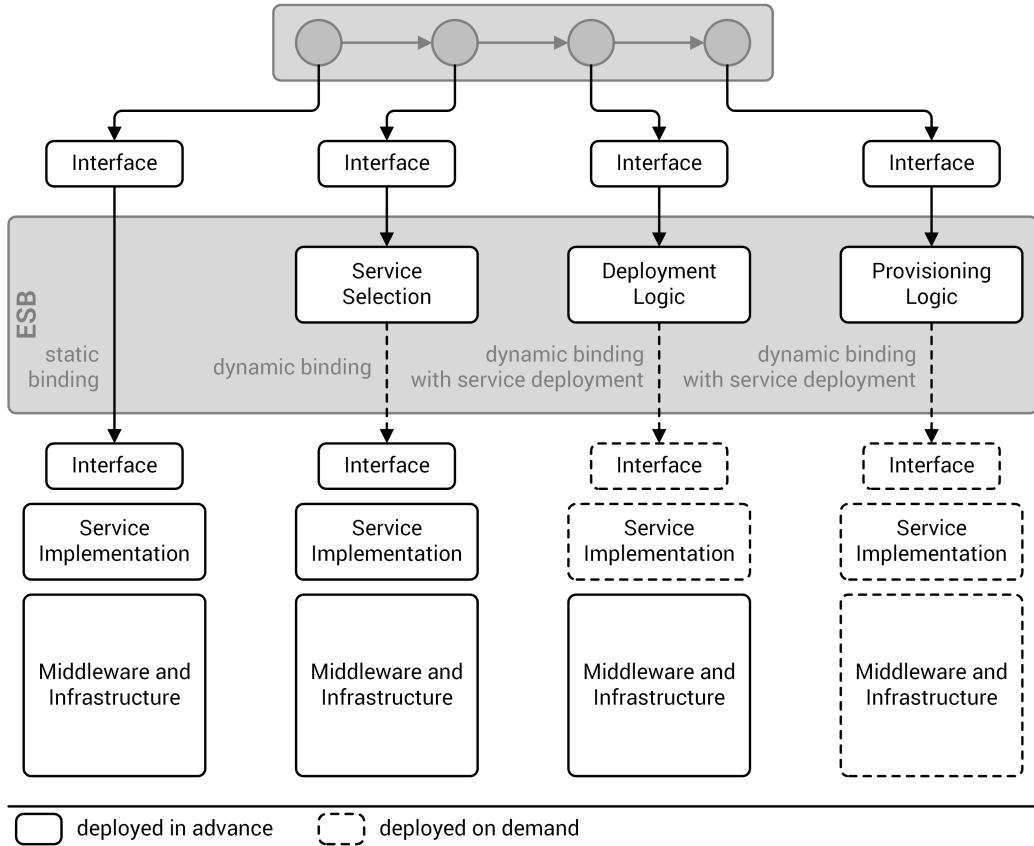


Figure 3.1: Simplified overview of service binding strategies [based on 35].

similar to the already existing dynamic binding with service deployment strategy, but adds the dynamic provisioning of the middleware and infrastructure required by the service [35].

Their approach for dynamic provisioning and deprovisioning of workflow middleware and simulation services is separated into six steps, as can be seen in Figure 3.2. The first step is to model and start the execution of a simulation workflow using a local modeling tool like the SimTech Modeler. In the second step, the middleware for executing the workflow, e.g. the SimTech SWfMS, and its underlying infrastructure are provisioned to a cloud environment. Now, the workflow can be deployed on this middleware, which is step three. In step four, an instance of this workflow is executed. During this execution, a task might invoke some external service that is not yet available. The ESB determines this by checking the service registry, which stores information about available services. If the requested service isn't available, the ESB tells the provisioning engine to provision this service. The on-demand provisioning of services is step five, during which the provisioning engine retrieves the artifacts needed

3 Previous Work

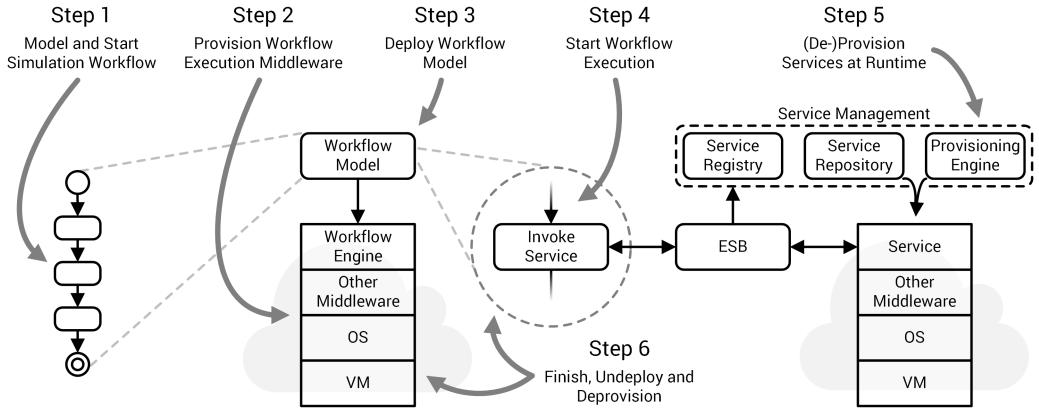


Figure 3.2: Steps during the on-demand provisioning of workflow execution middleware and simulation services [based on 35].

to provision the requested service from the service repository. The ESB then routes service calls and responses between the invoking workflow activity and the service. The service is also deprovisioned by the provisioning engine if it is no longer needed. The final step is to deprovision the workflow model and the workflow execution middleware after the execution of the workflow instance is finished [35].

The architecture they present, shown in Figure 3.3, can be separated into a local part at bottom and a cloud part at the top, as well as different phases. The bars at the bottom of Figure 3.3 show, which components are active during which phase [35]. Figure 3.3 shows that the only local components are the modeler and the bootware, while all other components are hosted in the cloud. In the modeling phase, a scientist uses local modeling and monitoring tools in combination with cloud hosted repositories and registries to create a workflow. These components are always running. When they start the execution of the workflow, the local bootware component kicks off the on demand provisioning process and therefore the second phase, called middleware runtime phase. In this phase, the bootware deploys a provisioning engine in the cloud (step 1), which in turn deploys the workflow middleware (step 2). Once the middleware is up and running, the workflow can be executed. During the execution, the ESB receives service calls from the workflow engine. Services that are not running at this time can then be provisioned by the provisioning engine (step 3). This takes place in the third phase, the service runtime phase.

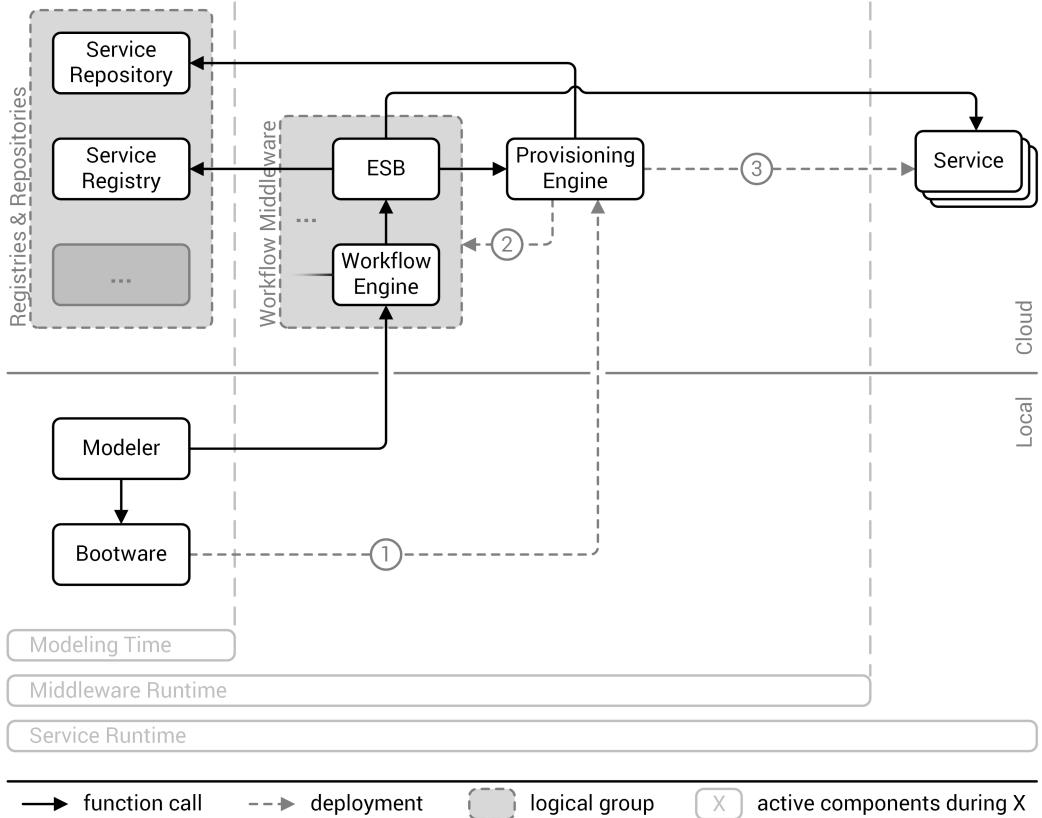


Figure 3.3: Proposed architecture [based on 35].

3.2 Dynamic Provisioning of Web Services for Simulation Workflows

Schneider found some problems with the architecture proposed in Section 3.1 [28]. The original architecture assumes that only one provisioning engine is used at a time. It neglects situations where services might require another (or multiple other) provisioning engines, because their provisioning descriptions aren't available in a format that the currently used provisioning engine understands. It also assumes that the ESB communicates directly with this provisioning engine to deploy and undeploy other services. This implicates that the ESB understands all manner of interfaces provided by various provisioning engines [28].

It further assumes that every provisioning engine knows how to communicate with the service repository to get the information and resources it needs to provision a service. While this might be true for some provisioning engines, it's certainly not true for all of them. This problem

is further amplified because there are no standards defined for such a service repository [28].

Another assumption of the original architecture is that a provisioning engine always understands the format of the service packages provided by the service repository. Different provisioning engines use different formats which are in general not compatible. If provisioning engines would all use a standardized format (like CSAR), this would not be a problem, but that isn't the case [28].

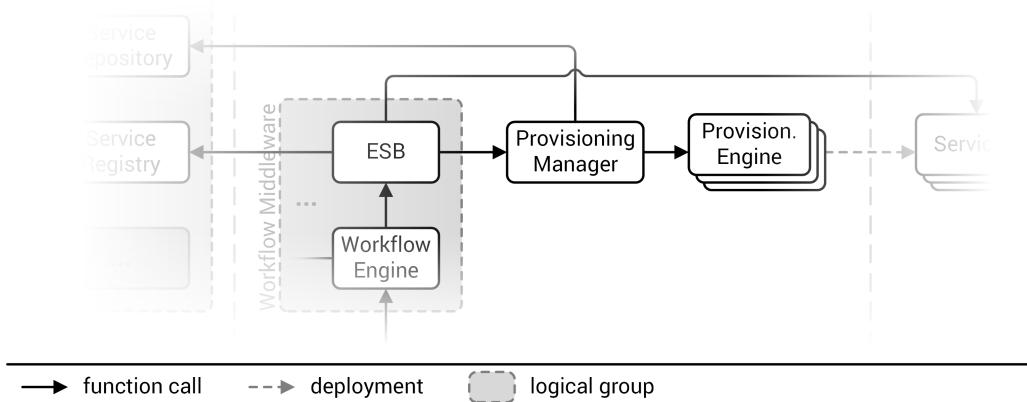


Figure 3.4: Extended architecture with added provisioning manager [based on 36]

Schneider further refines the previously shown middleware architecture by adding a provisioning manager as intermediary between the ESB and the provisioning engines [28]. Figure 3.4 shows an excerpt of the extended architecture with the additional provisioning manager at the center. This addition improves the original architecture in three aspects.

The ESB can now use the stable interface of the provisioning manager to trigger provisioning engines instead of calling those provisioning engines directly. The provisioning manager handles the differences between the provisioning engines. This makes it also possible to use multiple different provisioning engines during one workflow execution. The provisioning manager also handles the communication with the service repository or possibly multiple service repositories for different provisioning engines. It can provide information to a particular provisioning engine if it cannot get the information it needs from the service repository on its own. The provisioning manager could also translate different service distribution formats so that provisioning engines could be used with formats that they don't support [28].

4 Related Work

This chapter summarizes related work of other authors that is of interest to this thesis. We take a look at a paper that presents work similar to this diploma thesis.

Another diploma thesis that is worked on in parallel to this diploma thesis is designing the provisioning manager that was described by Schneider. [more ...titel, ref, summary](#)

4.1 Architecture for Automatic Provisioning of Cloud Services

Kirschnick et al. present an extensible architecture for automatic provisioning of cloud infrastructure and services at different cloud providers. They define a cloud service as a number of software components, their configuration, and the cloud infrastructure they are running on. Therefore, to provision a cloud service, one must first provision the cloud infrastructure, then install the software components and finally configure them. For this process they designed a so called service orchestrator [20].

Figure 4.1 shows a simplified overview of the service orchestrator architecture. Users can submit service models via a service API, shown at the bottom of Figure 4.1. The service model describes the topology of a cloud service, the components it consists of and their configuration. This model is used by the service orchestrator to provision new cloud services and to trigger reconfiguration and topology changes of existing services [20].

The service orchestrator is build in two layers. The orchestration layer, shown at the bottom of Figure 4.1, picks up the service model and delegates the different steps that are necessary to provision the cloud service to the abstraction layer. The deployment steps will be executed in parallel wherever dependencies allow it. The abstraction layer, shown in the middle of Figure 4.1, provides abstract methods to handle the management, installation, configuration, and starting of software. It consists of five different managers for infrastructure, packages, applications, configuration, and VM connections [20].

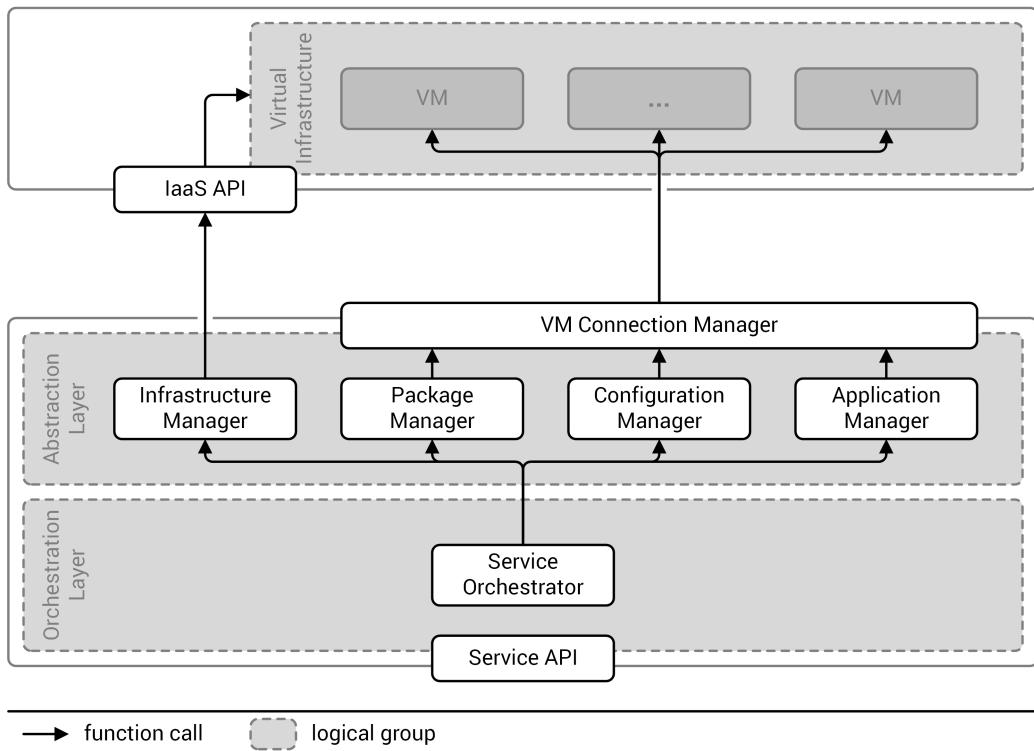


Figure 4.1: Simplified architecture for automatic provisioning of cloud services [based on 20]

The infrastructure manager abstracts away different APIs of cloud providers for provisioning cloud infrastructure. It is used to create new VMs at a specific cloud provider, shown at the top of Figure 4.1. These can then be used by the other managers to create the requested cloud service. The VM connection manager offers a unified interface for different communication methods, for example SSH, Remote Desktop Connection (RDC), Virtual Network Computing (VNC), and Telnet. The package, configuration, and application managers use the interface provided by the connection manager to send their commands to the VMs at the cloud provider [20].

The package manager can install software packages in different environments, for example with existing package managers like Advanced Packaging Tool (APT), or directly on the file system. The configuration manager offers a unified interface for component specific configuration methods, such as file templates or configuration APIs. The application manager manages the state of software components, i.e. starting and stopping them. Together, these managers can install, configure, and manage the requested cloud service on the VMs provided by the cloud provider [20].

5 Requirements and Constraints

In this chapter we present the requirements and constraints that shape the development of the bootware. We begin with the requirements, which were explicitly given at the beginning of this thesis. Then, we describe additional constraints which we added to limit the scope of the work.

5.1 Requirements

The main goal of this thesis is to lay a foundation by creating the core design of the bootware. It was clear from the beginning that because of the limited time available not every feature that might be necessary for the full operation can be fully implemented. Instead, the foundation we develop here should keep future needs in mind and make it simple to extend the bootware when needed. It is therefore a core requirement to keep the bootware relatively generic and make it extensible where necessary.

It should be extensible in two key areas, namely the support for different cloud providers and for different provisioning engines. For this thesis, Amazon is the only cloud provider that has to be supported, but it has to be possible to add others in the future. Concerning provisioning engines, only OpenTOSCA has to be supported for now, but again with the possibility to add more in the future.

It is also important that the bootware is easy to use. In fact, it should be practically invisible whenever possible. It should hook into the already existing process of executing a workflow without adding unnecessary interaction steps when possible. However, it can't be hidden completely, because the user has to specify a cloud provider and the corresponding log-in credentials somewhere. The user should also get some feedback about the progress of the deployment, because this process might take some time and might seem unresponsive without frequent status updates.

A further requirement is that the bootware should be relatively lightweight and open standards

should be used where possible. In this case, lightweight means that the bootware should be small, independent program that does not require a huge supporting infrastructure to be executed. It should also be easy to distribute and setup and it has to be able to run on an average personal computer.

5.2 Constraints

The bootware could theoretically be written in any major programming language but we limit our selves to Java. The reason for this is that all the other SimTech components are written in Java, so by also using Java we fit nicely into this already existing ecosystem. Additionally, for things like Eclipse integration we would have to use Java anyway. We also have to keep in mind that the bootware will not be finished with this thesis. Other people will have to extend it in the future and since Java is common in general, as well as in the SimTech project, it makes sense to use it instead of another programming language. We can further narrow our use of Java by limiting us to Java 1.6. This also has to do with the already existing parts of the SimTech project, that are geared towards this version as well. Using another version of Java could lead to unforeseen incompatibilities. We also constrain the bootware usage to one bootware per user. We don't plan for multi-tenancy, i.e. multiple users using the same bootware. In the next chapter we will also introduce additional constraints that became necessary during the design process and will therefore be explained at the appropriate times.

6 Design

In this chapter we will develop the design of the bootware. This design is held intentionally abstract. Some specific implementation details will be described in Section 8.3.

6.1 Component Division

As described in Section 3.1, the proposed architecture initially only envisioned one bootware component. This architecture was expanded with the introduction of the provisioning manager, as described in Section 3.2. At this stage, the provisioning manager included all the functionality necessary to provision and deprovision provisioning engines in the cloud, in addition to the functionality already mentioned in Section 3.2. This was a somewhat convoluted design where multiple responsibilities were mixed into one component. It was later decided that the provisioning manager should be split into two parts. The actual provisioning manager handles the communication with the service repository and the various provisioning engines, as described before in Section 3.2. A separate bootware component handles the provisioning and deprovisioning of the provisioning engines. At the moment, that leaves us with two bootware components, one local and one remote, where the local bootware kick-starts the remote bootware, which then handles the actual provisioning of provisioning engines. The first question that has to be answered is whether this division is reasonable, or if another alternative makes more sense. We will now discuss the viability of four such alternatives.

6.1.1 Single Local Component

First we consider the simplest case: A single local component as shown in Figure 6.1. In this scenario, all provisioning processes are initiated from a component installed locally on the users machine, alongside or as part of the workflow modeler.

The advantages of this architecture lie in its simplicity. Only one component has to be created and managed. We wouldn't have to deal with bringing the bootware into a cloud environment

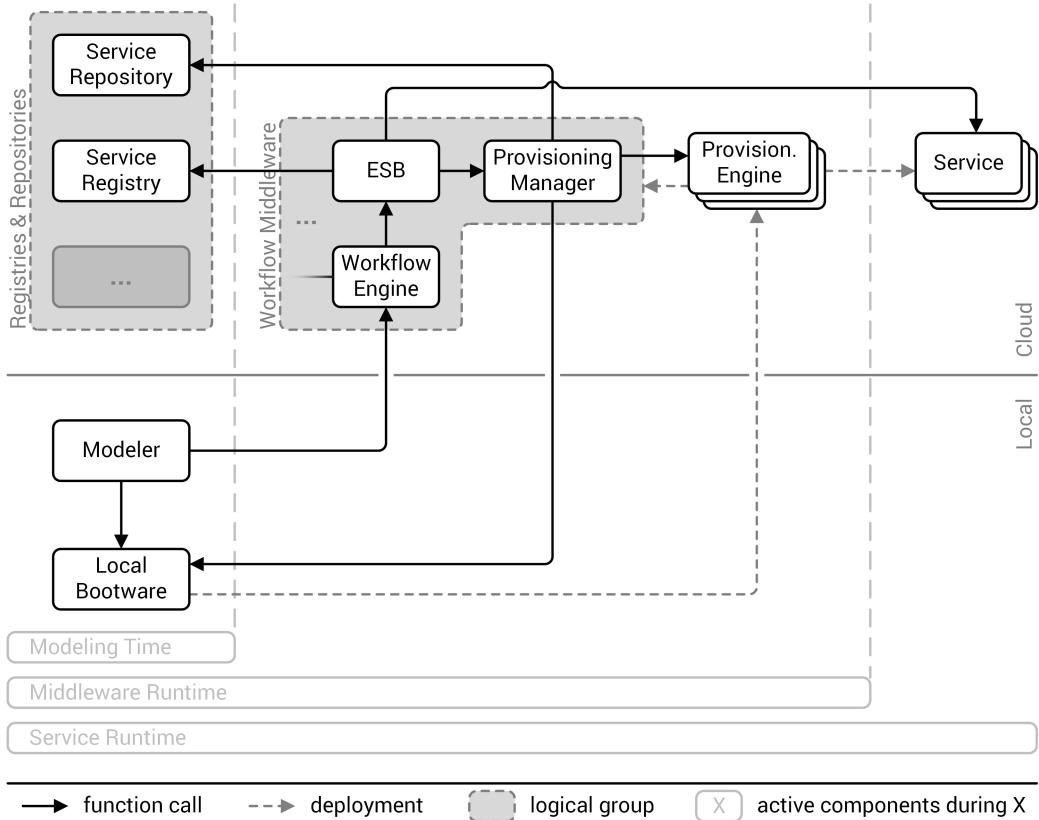


Figure 6.1: Simplified overview of the single local component architecture

and each user would have his own personal bootware instance, so multi-tenancy wouldn't be an issue. There is no possible overlap in functionality, as it would be the case in a 2-tier architecture and communication between multiple bootware components doesn't have to be considered.

The disadvantages are caused by the component being local. Since all the functionality is concentrated in one component, it can become quite large and complicated, which is one thing that should be avoided according to the requirements. A much bigger problem however is the remote communication happening in this scenario. As Figure 6.1 shows, all calls to the bootware from the provisioning manager would leave the remote environment. Also, all calls from the bootware to the provisioning engines would enter the remote environment. This type of split communication can be costly and slow, as shown by Li et al. [21]. They compared public cloud providers and measured that intra-datacenter communication can be two to three times faster and also cheaper (often free) compared to inter-datacenter communication [21].

6.1.2 Single Remote Component

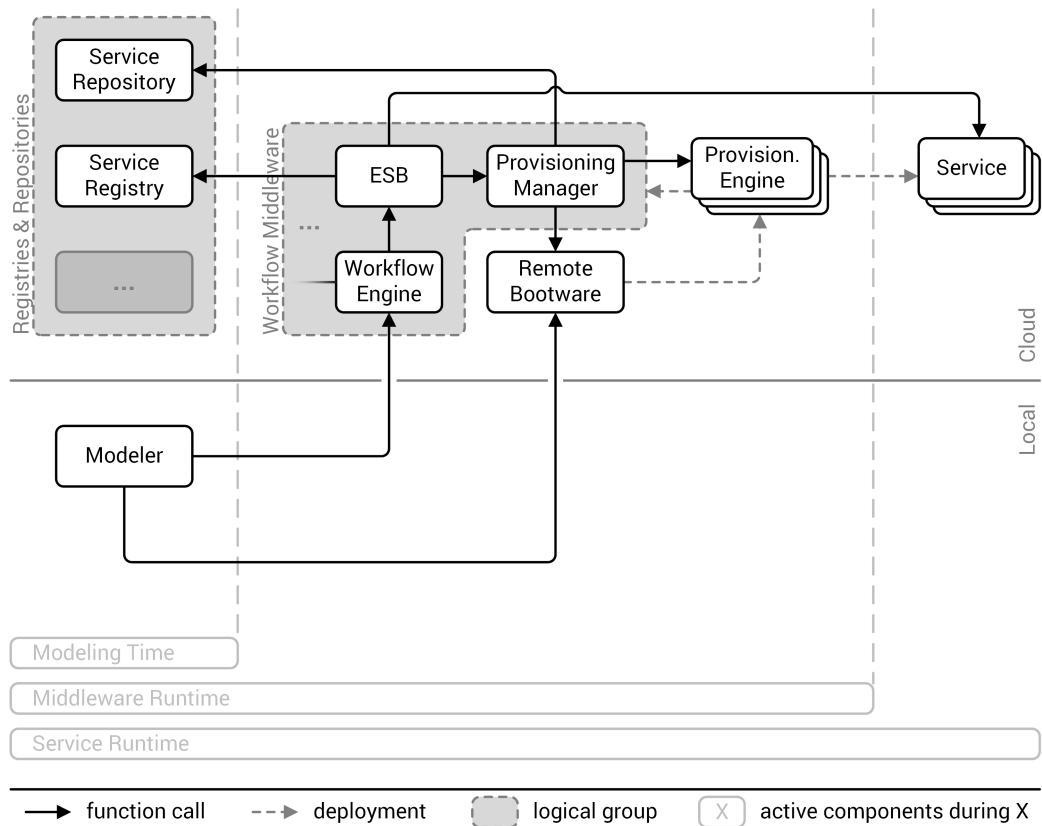


Figure 6.2: Simplified overview of the single remote component architecture

The next obvious choice, as displayed in Figure 6.2, is to put the single bootware component into a remote environment, where the disadvantages of local to remote communication would disappear. However, this creates new problems.

Since there aren't any additional components in this scenario that could manage the life-cycle of the remote bootware, the user would have to manage it by hand, which leads to two possibilities. Either the user provisions the bootware once in some cloud environment and then keep this one instance running, or they provision it once they need it and deprovisions it when they are done.

In the first case the user would only have to provision the bootware once, but this creates a new problem: The user doesn't know where exactly to put the bootware. Since one requirement is that multiple cloud environments should be supported, it is possible that the bootware is not located anywhere near the cloud environment where it should provision further components.

The communication problem of the single local bootware component can still occur in these cases. While the other approaches presented here don't completely eliminate this problem, they at least have the option to move the bootware with each individual bootware execution, while in this first case, the bootware would stay in one place for multiple, possibly many bootware executions.

Another problem is that the bootware would be running all the time, even if the user doesn't need it, which would increase costs. This problem could be reduced if this bootware instance is shared with others to assure a more balanced load. But then the user would have to manage some sort of load balancing and the bootware would have to support multi-tenancy or be stateless to be able to cope with potential high usage spikes. This would further complicate the design and implementation of the bootware and possibly increase the running costs.

In the second case, the user would provision the bootware whenever they need it. Now the user would be able to pick a cloud environment that is close to the other components that they plan to provision later. This eliminates the two major problems of the first case but increases the effort that the user has to put into a task that they shouldn't have to do in the first place. Life-cycle management of the bootware should be automated completely and hidden away from the user. Therefor, this scenario is not appropriate for our case.

6.1.3 2-Tier Architecture

Next, we take a look at a 2-tier architecture, as shown in Figure 6.3, where the bootware is divided into two components. On the local side we have a small and simple component which has mainly one function: To provision the larger second part of the bootware in a remote environment near to the environment, where other components will be provisioned later.

This eliminates the problems of a single local or remote bootware component. The user no longer has to be involved in the management of the remote bootware since the local bootware handles all that. Since we provision the remote bootware on demand, we now also can position the remote bootware close to other remote components to minimize local/remote communication and the problems resulting of it. We can now keep the local part as simple as possible and make the remote part as complicated as it has to be and since we provision the remote bootware only for one user, we don't have to worry about multi-tenancy.

But we also introduce new problems. For one, we now have duplicate functionality between the two components. Both have to know how to provision a component into multiple cloud environments. The local bootware has to be able to put its remote counterpart into any cloud environment. The remote bootware has to be able to provision other components into the

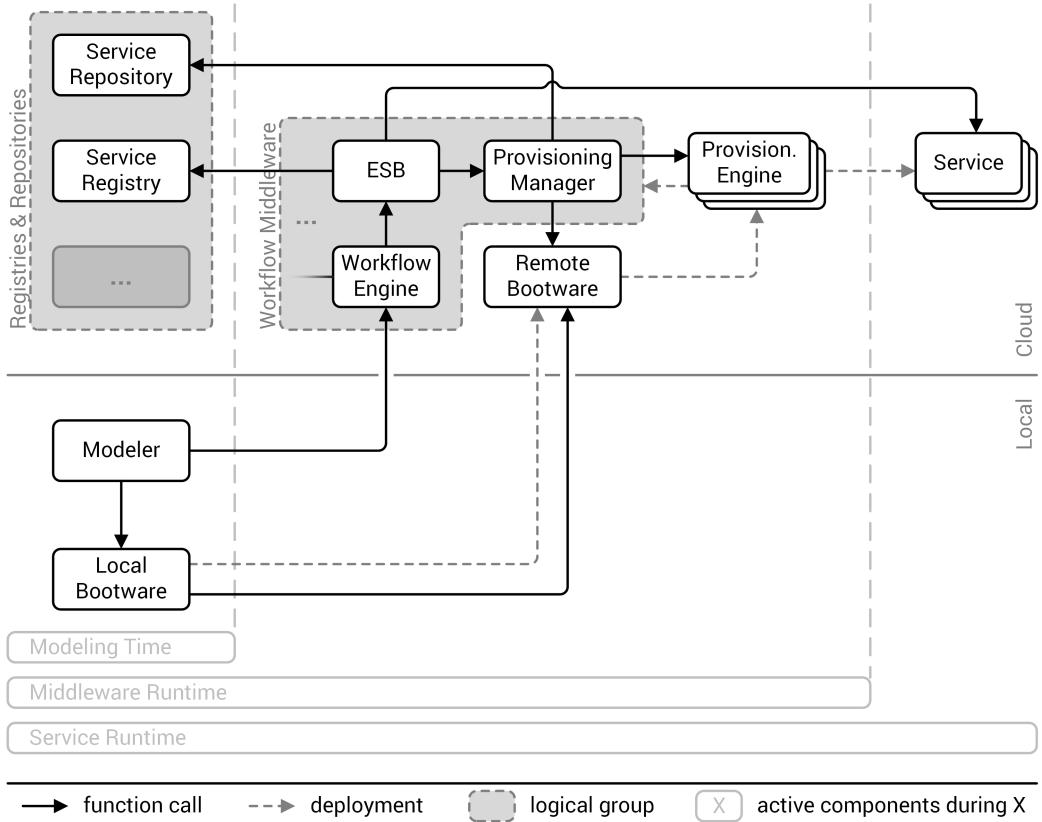


Figure 6.3: Simplified overview of the 2-tier architecture

same environment in which it runs (ideally, to minimize costs). Since itself can be located in any cloud environment, it has to be able to do this in any cloud environment. Independent from this, it also has to be able to provision to any environment that the user or the service package chooses. But this problem can be solved by using a plugin architecture, which allows both components to use the same plugins. We discuss plugins in detail in Section 6.4. A second problem which we can't avoid but can solve is the communication which is now necessary between the different parts of the bootware. More on this in Section 6.3

6.1.4 Cloning

This architecture can be seen as an alternative form of the 2-tier architecture described in Subsection 6.1.3. In this case, there are also two bootwares working together and the remote bootware does most of the work. However, the local and the remote bootware are

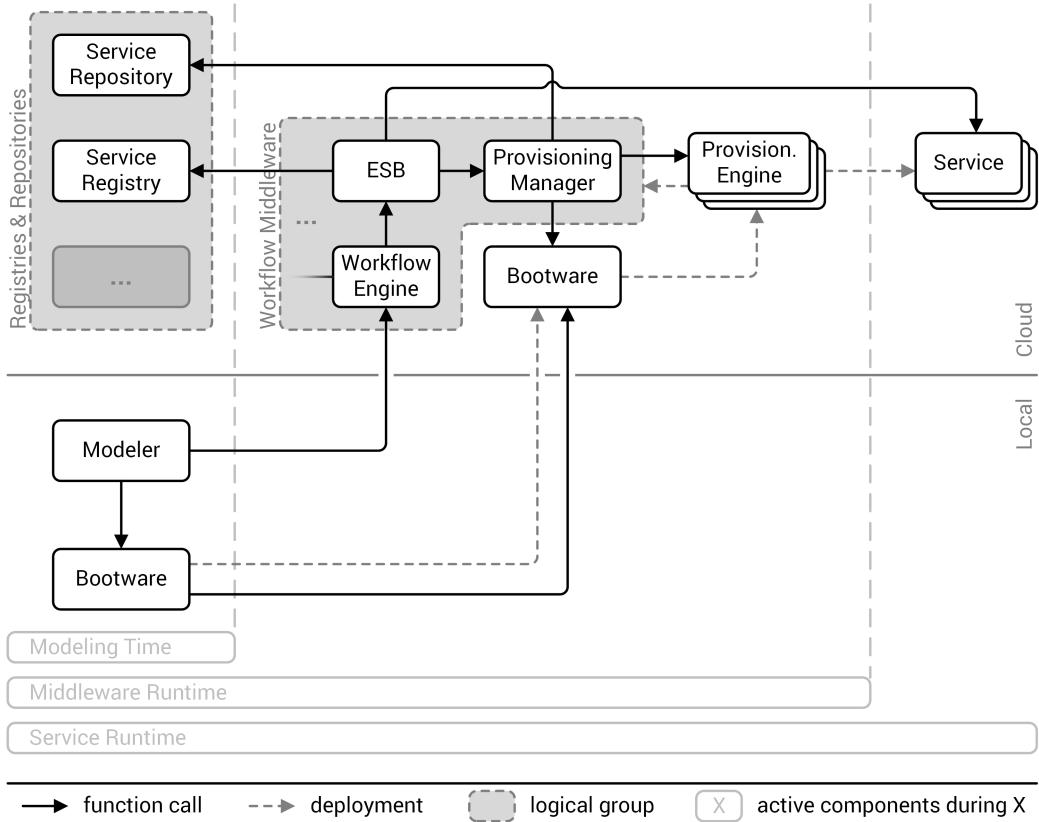


Figure 6.4: Simplified overview of the cloned component architecture

identical, as shown in Figure 6.4. Instead of provisioning a bigger bootware in a remote environment, the local bootware clones itself. Compared to the 2-tier architecture described before, this has the advantage that only one component has to be designed and implemented. Duplication of any functionality wouldn't therefore be an issue. The disadvantage would be that the local bootware would be exactly as complex as the remote bootware and might contain functionality that it wouldn't require for local operation and vice versa. However, since we want to keep the whole bootware, including the remote part, fairly lightweight, it is unlikely that the complexity of the remote bootware will reach such heights that it could not be run on an average local machine. In this case, the advantage of only having to design and implement one component seems to outweigh the disadvantage of a slightly more complex local component (compared to the 2-tier variant). Of course, this architecture makes only sense if the functionality of the two separate components in the 2-tier architecture turns out to be mostly identical. Therefore we can't decide yet if this architecture should be used.

6.1.5 Decision

Of the four alternative presented here, alternative three - the 2-tier architecture - makes the most sense. Therefore it is selected as the alternative of choice and used for further discussion. We do however retain the option to transform it into alternative four, if we discover that both components share much of same functionality. But this can only be judged at a later stage, when we know exactly how the internal functionality of the bootware will work.

6.2 Modeler Integration

Looking at Figure 6.3, we can see that the first interaction with the bootware is the call from the Modeler to the local bootware, which starts the bootstrapping process. So in this section we are going to take a look at the integration between modeler and bootware in more detail. The first question we face is: Why even divide the modeler and the local bootware? Why not integrate the local bootware functionality into the modeler? We go this route, because we want the bootware to be as generic as possible. The modeler in Figure 6.3 is not a specific modeler and in theory it should be possible to use the bootware with any modeler (and any workflow middleware) without too much modification. So by keeping the bootware as a separate generic component and only implementing a small, modeler specific adapter, we are able to support different environments without changing the core bootware components. We call this abstract concept the bootware adapter.

In Chapter 5 we mentioned that the bootware should hook into the already existing deploy process in the modeler. How this deployment process works depends on the actual modeler that is used, so at the moment, we can't say how exactly we can integrate in this process. Specific integration details for our modeler, the SimTech Modeler, will be discussed in Section 8.1. We know however what needs to happen in the bootware adapter to get the bootstrapping process going.

First, the bootware adapter has to start the local bootware so that it will be in a state where it can receive and process requests. This is shown in Figure 6.5 as deployment operation from the bootware adapter to the local bootware and involves starting an executable and maybe passing along some sort of configuration file. Once the local bootware is running, the bootware adapter has to set up the context for the following requests. This includes telling the bootware configuration details, like the credentials for all cloud providers that will be used. Once this is done, the modeler has to make one request to the local bootware, containing the cloud provider, the provisioning engine, and the package reference for the workflow middleware,

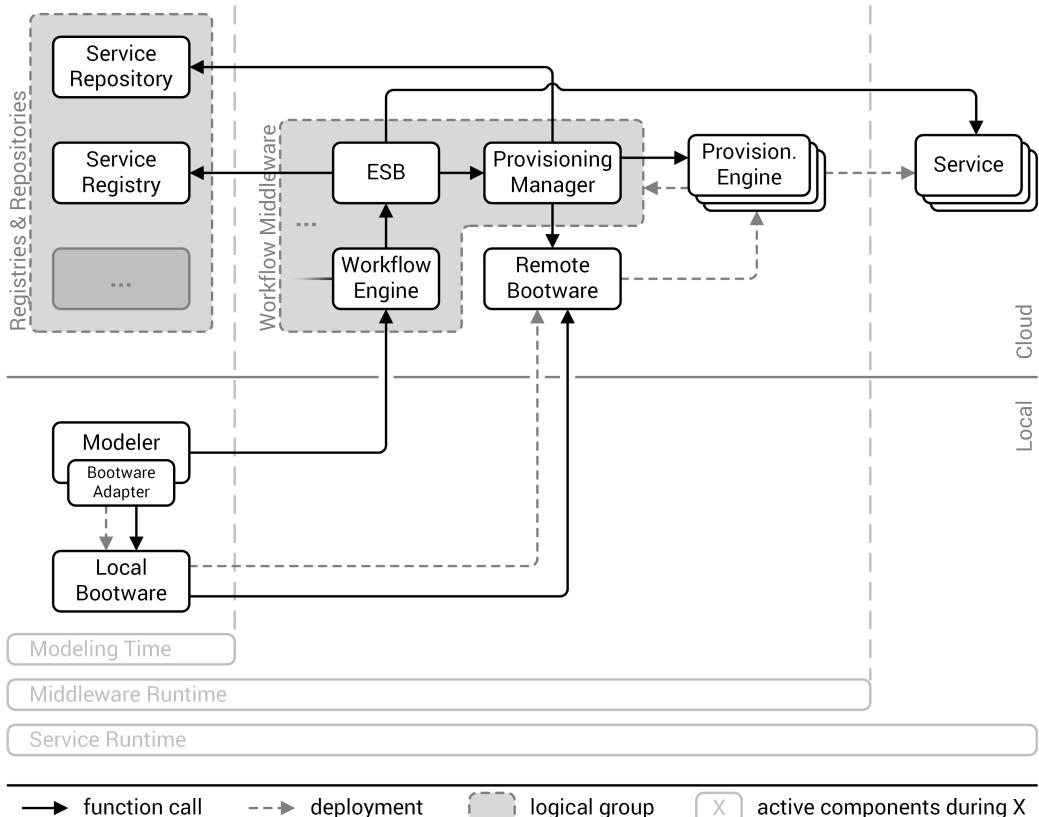


Figure 6.5: Modeler integration with a plugin.

which is shown in Figure 6.5 as function call from the bootware adapter to the local bootware. The local bootware will take this information and provision the remote bootware, a provisioning engine, and the workflow middleware in the specified cloud environment. If successful, it returns the endpoint references of the workflow middleware to the bootware adapter, who then has to set up the modeler to use these references for the actual workflow deployment.

This is the minimal work the bootware adapter has to do to kick off the bootstrapping process. Additional functionality can be implemented if desired, but is not necessary for the core bootstrapping process. This additional functionality could include user interface integration, additional bootware management functionality, etc. The function call in Figure 6.5 assumes that there exists some interface in the local bootware that is accessible from the outside. In the next section we will discuss how this external communication mechanism will be implemented.

6.3 External Communication

In Section 6.2 we established that a bootware adapter in the modeler has to call the local bootware. From Section 6.1 we also know that both the local bootware and the provisioning manager have to call the remote bootware. We now have to decide, how this external communication with the bootware will work. There are several factors that impact this decision. Communication between the components should be as simple as possible, but has to support some critical features. To keep it simple, it would make sense to use the same communication mechanism for communication between the bootware components as well as with other external components, like the provisioning manager and the bootware adapter.

Since the provisioning processes kicked off by the bootware can potentially take a long time to finish (in the range of minutes to hours), we face possible timeouts when using synchronous communication. As alternative we could use asynchronous communication with callbacks. This would avoid timeouts but also creates a new problem. The callback message send as response is separated from the original message and therefore appears as unsolicited message to the client. If the client is rejects unsolicited messages, for example because he is located behind a firewall, the callback message might also be blocked. This could be a problem, since in the environment where the bootware will most likely be used, i.e. at universities, secure networks are very common and asynchronous callbacks could therefore be problematic. Another solution is to use polling, i.e. after a request was sent to the bootware, the bootware is polled periodically for a response. This also avoids timeouts as well as the firewall problematic. Disadvantages of polling, for example when many clients poll a server at the same time and cause a bottleneck, will most likely not be a problem in our case, since we only have a very restricted number of clients for each bootware instance and no multi-tenancy. Since the provisioning process can take very long, there should also be some mechanism to get feedback on the current status during a long running provisioning process.

The communication with the bootware components will contain sensitive data, for example login information for cloud providers. This information has to be provided from the outside and should be transported securely to prevent malicious or fraudulent attacks. The selected communication method therefore has to support some sort of security mechanism, ideally end-to-end encryption. While these security mechanisms will not be used in this thesis due to time constraints, selecting the right communication method is still critical for future development.

Java provides a package for Remote Method Invocation (RMI)¹, which allows objects in one Java VM to invoke methods on objects in another Java VM. Depending on the implementation,

¹http://docs.oracle.com/javase/7/docs/api/java/rmi/package-summary.html#package_description

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it can be used with polling or asynchronous callbacks. But since RMI is limited to Java and we might want to communicate with the bootware from a component written in another programming language, RMI doesn't seem like a good fit. For communication between programs written in different languages we could use the Common Object Request Broker Architecture (CORBA), a standard defined by the Object Management Group (OMG). It supports mappings for common programming languages, like Java, C++, Python, and others. CORBA also supports polling and asynchronous method invocation via callbacks [1], as well as transport layer encryption and other security features [9].

As a second alternative, we could communicate with messages by using message-oriented middleware. As explained earlier in Section 2.4, it supports communication between different components using adapters and channels. Asynchronous communication is supported by using message queues for temporary storage. The middleware can also provide additional persistent storage and backups for high availability [10]. It may also support security features like encryption. Another alternative are web services via Simple Object Access Protocol (SOAP) or Representational State Transfer (REST). Like CORBA, web services also support polling and asynchronous invocation, as well as security mechanisms [37].

Since the whole SimTech SWfMS already uses SOAP based web services, it would make sense to also use SOAP based web services as external communication mechanism for the bootware. The technology and knowledge is already in place and introducing a second mechanism like CORBA would unnecessarily increase the complexity of the project, especially since CORBA doesn't offer any significant advantages over SOAP based web services. Using a message-oriented middleware would also be an option but introducing another component seems to complicated, especially since we don't need most of the features that it offers (e.g. transactions, persistence, etc.). Figure 6.6 shows the addition of web service call and return communication between the bootware adapter and the local bootware, and between the remote bootware and the local bootware, as well as the provisioning manager. With polling, long running provisioning processes won't pose a problem. We do however still need information during those long running processes to give the user some feedback. For this, a secondary communication mechanism which supports sending multiple feedback messages has to be used.

This secondary communication channel could take any form, but a natural choice for publishing the intermediary state of the bootware would be a message queue system. In this case, the remote bootware pushes messages to a message queue to which the local bootware (and other components if needs be) can subscribe to receive future messages. Figure 6.7 shows the proposed architecture with an additional (and optional) message queue that allows the local bootware or other components to listen to status updates from the remote bootware. Since it is not necessary for the successful use of the bootware, it would make sense to

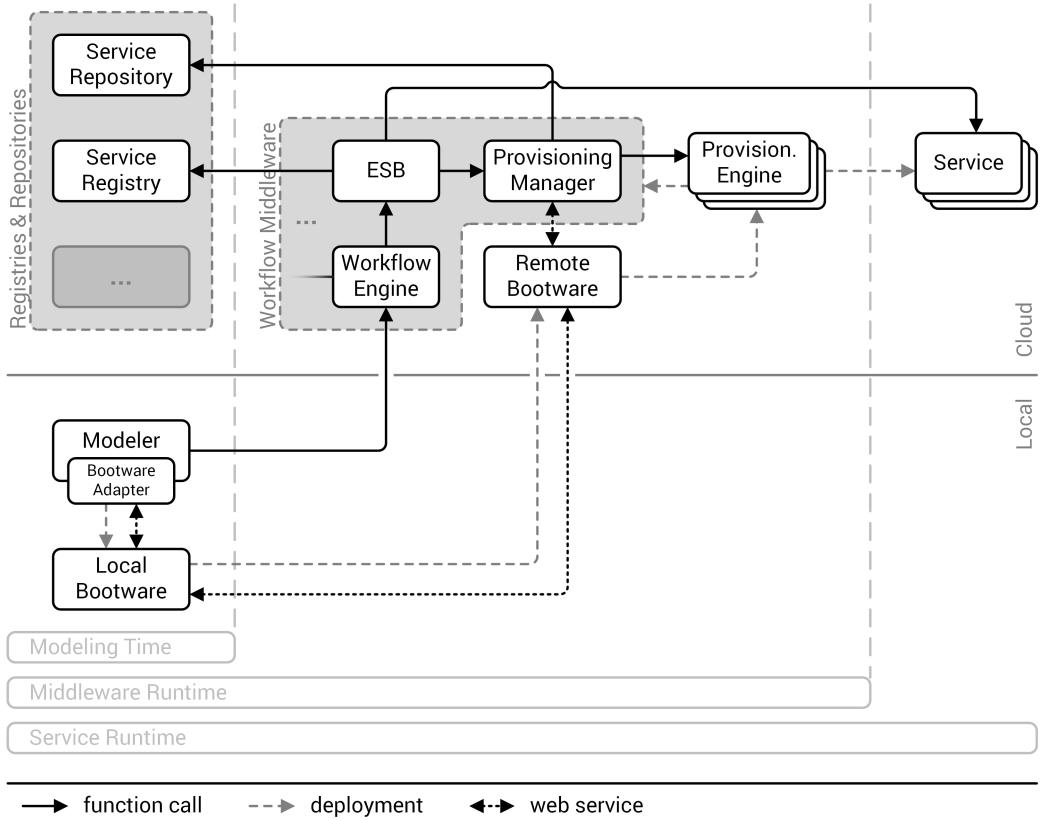


Figure 6.6: Simplified overview of the 2-tier architecture with web service communication

implement this secondary communication mechanism as an extension to the bootware. This extension would not be part of the core bootware, but rather an additional component that could be used when needed. This would allow us to add arbitrary communication extensions to the bootware depending on future needs. How this can be done will be discussed in the next section.

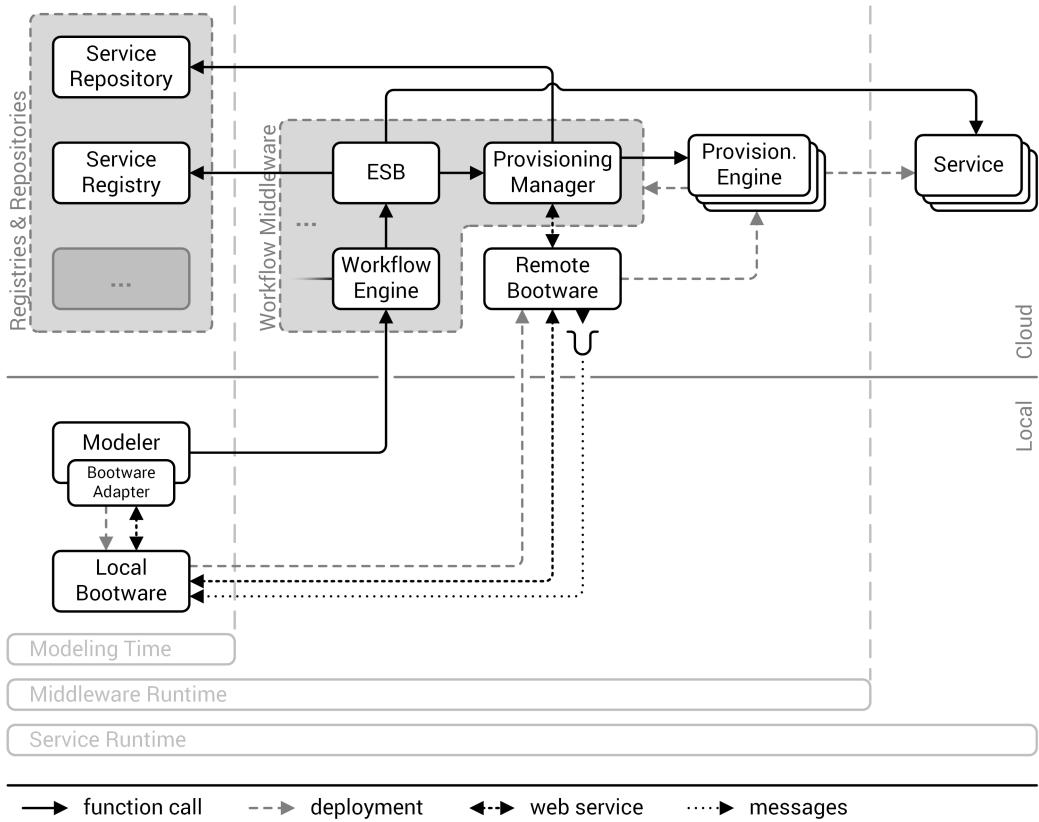


Figure 6.7: Simplified overview of the 2-tier architecture with web service and messaging queue communication

6.4 Extensibility

In Section 6.3 we mentioned a secondary communication mechanism that would be best implemented in form of an extension to the bootware. The requirements for the bootware also state that support for different cloud environments and provisioning engines should be achieved through means of software engineering. These requirements are intentionally vague to allow for the selection of a fitting extension mechanism during the design process. In this section we will take a look at different extension mechanisms for Java and pick the one that suits our needs best.

6.4.1 Extension Mechanisms

The simplest way to fulfill the extensibility requirement would be to create a set of interface and abstract classes to define the interfaces and basic functionality that are necessary to work with different cloud environments and provisioning engines. These interfaces and abstract classes would then be implemented separately to support different scenarios and would be compiled, together with the rest of the application, into one executable. At runtime, a suitable implementation would be selected and used to execute the specific functionality required at this time.

This extension mechanism is simple, but restricted by its static nature. The entire executable has to be recompiled if any implementations are changed or added. This may not be a problem if the set of possible extensions that have to be supported is limited and known at the time of implementation or if it changes rarely. If the set of necessary extensions is unknown or changing from time to time, implementing new or changing existing extensions can get cumbersome, since a new version of the whole software has to be released each time. It would be far better if extensions could be implemented separately from the core bootware components and added and removed at will.

A more flexible architecture is needed, for example a plugin architecture. Interfaces for the extension points still exist but the extension are no longer part of the main bootware components. They are compiled separately into plugins that can be loaded into the main bootware components on the fly. There are several possibilities to realize such an architecture.

It is certainly possible to implement a plugin framework from scratch. An advantage of this approach would be that the design of the plugin architecture could be tailored to our use case and would be as simple or complex as needed. But there are also several disadvantages. For one, we would reinvent the wheel, since multiple such frameworks already exist. It would also shift resources away from the actual goal of this thesis, which is designing the bootware. Furthermore it would require a deep understanding of the language used for the implementation (in this case Java), which is not necessarily given. Therefore it seems more reasonable to use one of the already existing plugin frameworks. Which one exactly will be determined later in Subsection 8.3.1.

6.4.2 Plugin Repository

Now that we have introduced plugins we face new problems. Figure 6.8 shows the current architecture, where both bootware components use their own plugins. If a plugin is added

or updated, the user has to manually copy this plugin to the right folder of one or both of the bootware components. Furthermore, if both components use the same plugins, which they will (for example plugins for different cloud providers), we will have duplicate plugins scattered around. This is inefficient, probably annoying for the user and can cause errors if plugins get out of sync.

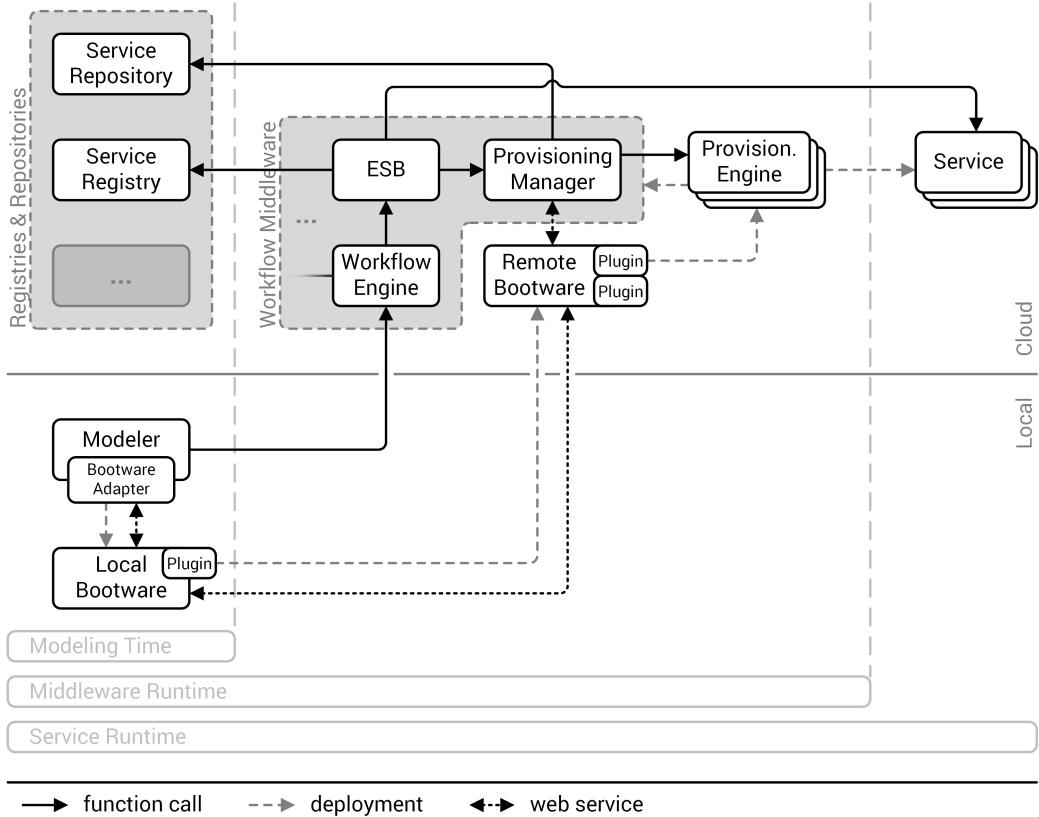


Figure 6.8: Simplified overview of the 2-tier architecture with plugins

To remedy this situation we introduce a central plugin repository, as shown in Figure 6.9. This repository holds all plugins of both components so it eliminates duplicate plugins. If plugins are added or modified it has only to be done in one place. Plugin synchronization can happen automatically when the bootware components start, so that the user is no longer involved in plugin management. The repository also enables easy plugin sharing, which was cumbersome earlier. While a central plugin repository is a sensible addition to the proposed bootware architecture, its design and implementation are out of scope of this thesis. This work is left for the future and the plugin repository will not be mentioned in any other figures apart from Figure 6.9.

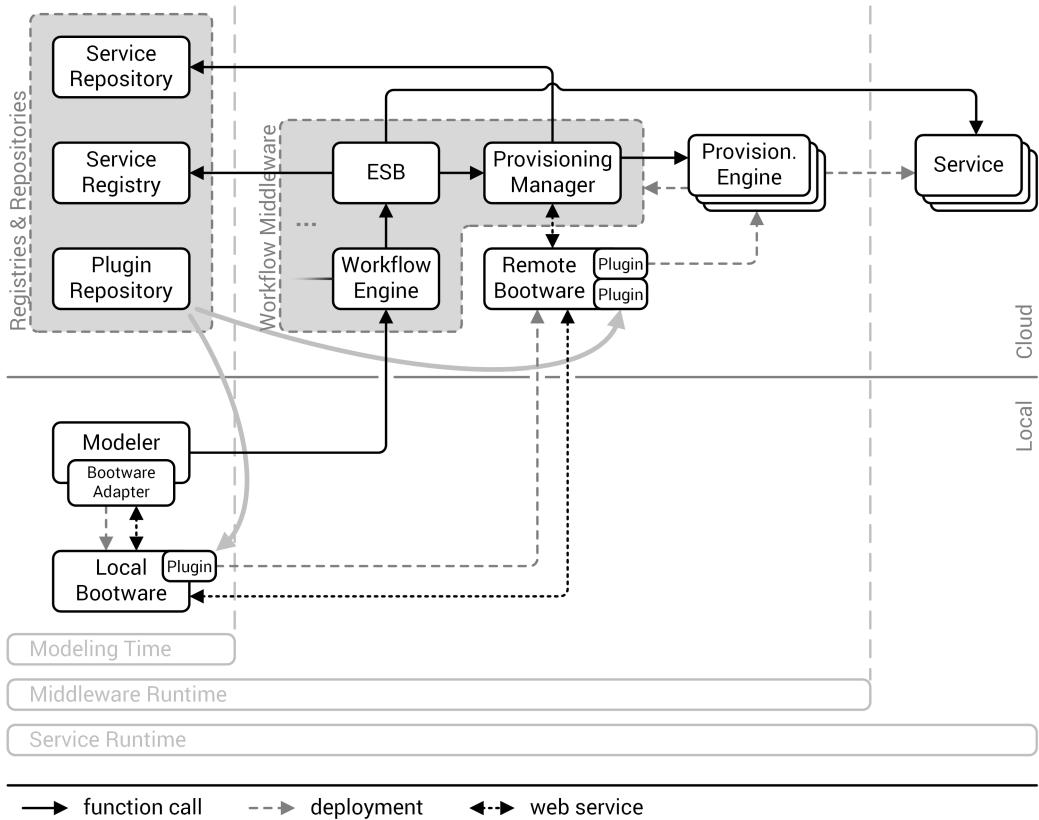


Figure 6.9: Simplified overview of the 2-tier architecture with a plugin repository

6.5 Plugin Types

We can already tell from the requirements that we must at least support two different plugin types, one for different cloud providers and one for different provisioning engines. The former are required because we may want to provision into different cloud environments. The latter are required because we might want to use different provisioning engines to do so.

The cloud provider plugins will be responsible for creating and removing resources in cloud environments and making them available for the user to configure and use. This could be bare bone VMs (like AWS EC2 instances), or PaaS environments (like AWS Beanstalk). We don't even have to constrain these plugins to cloud resources and can make them more abstract, as long as we can run the plugin and get an IP address to a computer resource that we can use. For example, we could also provide a plugin that starts and stops VMs on our local machine, which could be useful for quick and inexpensive local testing. So a better

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name for these plugins would be *infrastructure plugins*.

The same line of thinking can be used on the provisioning engine plugins. All that we care about is that we can get some software running on a given infrastructure and that we get back an URL where we can find this software once it is up and running. A better name for these plugins would therefore be *payload plugins*.

Now that we have infrastructure plugins and payload plugins, we should be able to provision the infrastructure we need and use payload plugins to install and run any software on it. But there is a step in between provisioning the infrastructure and installing the software that we are glancing over: We have to somehow connect to the infrastructure before we can install something. The connection functionality could be part of either the infrastructure plugins or the payload plugins, or it could be separated into independent connection plugins.

For the sake of efficiency and extensibility it would be best to use independent connection plugins. For example, if a user wanted to add a new connection type that should be used to install x applications in y environments, they could do so by writing one new connection plugin, instead of adding the functionality x -times to all payload plugins, or y -times to all infrastructure plugins. This would also reduce code duplication. Therefore, a third plugin type is necessary: The *connection plugins*.

The remote bootware also has to handle the initial provisioning of the workflow middleware, which involves calling a provisioning engine to tell it to start the provisioning process. Since this has to be done differently for all provisioning engines, it would make sense to also package this functionality into plugins that can be interchanged. We therefore introduce a fourth plugin type: The *call provisioning engine plugins*.

In Section 6.3 we also introduced the notion of secondary communication channels realized by plugins. We can generalize this into a more versatile fifth plugin type: The *event plugins*. These plugins are a bit less specific than the four other types. They allow users to add functionality that reacts to (or creates) events inside the bootware. How the actual event system will be implemented will be discussed in Section 6.6. With this fifth plugin type we have now covered all plugin types we will need. We will describe each plugin type in more detail, but before we do this, we will describe the common operations that all plugin types

have to implement.

| Operation | Input | Output | Description |
|------------|---------------|--------|---|
| initialize | Configuration | - | Is called by the plugin manager when the plugin is loaded |
| shutdown | - | - | Is called by the plugin manager when the plugin is unloaded |

Table 6.1: Common operations to be implemented by all plugin types

Table 6.1 shows the two common operations that all plugin types must implement. The initialize operation is called by the plugin manager when it loads a plugin. This operation can be used by plugin authors to initialize the plugin, for example by creating internal objects that will be used by other plugin operations later on. It takes a configuration object as parameter, which is taken from the request context. This allows the plugins to be configured from the outside if necessary. The shutdown operation is called by the plugin manager when it unloads a plugin. It can be useful to clean up plugin resources before the plugin is removed, for example by deleting temporary files or closing a connection.

6.5.1 Infrastructure Plugins

Infrastructure plugins are responsible for provisioning any infrastructure that the user wants to use during the bootware process. This could be VMs on a local machine, or IaaS or PaaS environments in the cloud. To be able to do this, an infrastructure plugin has to implement a range of functions using some API or SDK provided by the virtualization software or cloud provider.

Table 6.2 shows the operations a plugins of this type should implement. The deploy operation is responsible for deploying a resource and getting it to a state, where a connection to the resource can be established using a connection plugin. It takes no input parameters, but relies on the configuration passed to the initialize operation to get the configuration details it needs, like login credentials. If the deployment was successful, it returns an instance object, which contains information about the created instance, such as its IP address and login information.

The undeploy operation removes a resource that was previously deployed using the deploy operation. In case of a local VM this could mean that it stops the running VM. In case of a

cloud resource this could mean that it completely removes the resource so that no further costs are incurred. As input it takes an instance object created earlier by the deploy operation.

| Operation | Input | Output | Description |
|-----------|----------|----------|---|
| deploy | - | Instance | Deploys a connection ready instance of some resource and returns an instance object |
| undeploy | Instance | - | Completely removes a given instance |

Table 6.2: Interfaces to be implemented by infrastructure plugins

6.5.2 Connection Plugins

Connection plugins are responsible for creating a communication channel to previously deployed resources that can later be used by payload plugins to execute their operations on the resource. The connection could be made by using SSH, RDC, VPN, Telnet, or other communication mechanisms supported by the resource. The connection plugins should be implemented generically, so that they can be used for all kinds of resources.

Table 6.3 shows the operations that this type of plugin has to implement. The connect operation establishes a connection to a specific resource. The resource is specified by the instance object that is passed as input to the connect operation. If the connection was established successfully, the operation returns a connection object that can be used later by payload plugins to execute operations through this connection. The disconnect operation closes a connection that was previously established by the connect operation. As input, it takes a connection object that was previously created by the connect operation.

| Operation | Input | Output | Description |
|------------|------------|------------|--|
| connect | Instance | Connection | Establishes a connection to the given instance |
| disconnect | Connection | - | Disconnects a given connection |

Table 6.3: Interfaces to be implemented by connection plugins

6.5.3 Payload Plugins

Payload plugins are responsible for installing, uninstalling, starting, and stopping software on an infrastructure instance. This process can include the uploading of files and the execution of remote commands on an instance.

Table 6.4 shows the operations that plugins of this type should implement. The deploy operation installs a payload on an instance. This can include uploading files from the local machine or downloading files from other machines. To execute this operation, a connection to the instance is necessary, which is supplied as input with the connection object. The undeploy operation removes a payload from an instance. In most cases this will not be necessary, since the instance will be destroyed in the undeploy phase and with it all the payload data (assuming it wasn't installed in persistent storage). This method is provided for completeness and for special cases. The start operation starts a payload which previously was installed with the deploy operation. If the payload was started successfully, it returns the URL to the running payload. The stop operation stops the execution of a previously started payload. In most cases this will not be necessary, since the payload will be removed together with the instance in the undeploy phase. This method is provided for completeness and for special cases.

| Operation | Input | Output | Description |
|-----------|------------|--------|---|
| deploy | Connection | - | Deploys the payload over the given connection |
| undeploy | Connection | - | Undeploys the payload over the given connection |
| start | Connection | URL | Starts the payload over the given connection |
| stop | Connection | - | Stops the payload over the given connection |

Table 6.4: Interfaces to be implemented by payload plugins

6.5.4 Call Provisioning Engine Plugins

Call provisioning engine plugins provide the bootware with a unified way to call provisioning engines and trigger provisioning and deprovisioning operations. Table 6.5 shows the oper-

ations that these plugins should implement. The provision operation calls a provisioning engine and trigger the provisioning process. It takes two inputs: An endpoint reference, which points to the provisioning engine that should be used, and a service package reference, which points to the service package that the provisioning engine should provision. When completed successfully, the provisioning operation returns an endpoint reference to the just provisioned service. The deprovision operation calls a provisioning engine and triggers the deprovisioning process. It takes the same inputs as the provisioning operation, an endpoint reference to the provisioning engine and a service package reference.

| Operation | Input | Output | Description |
|-------------|--|--------------------|--|
| provision | Endpoint Reference, Service Package | Endpoint Reference | Tells the provisioning engine to provision the given service package |
| deprovision | Endpoint Reference, Service Package | - | Tells the provisioning engine to deprovision the given service package |

Table 6.5: Interfaces to be implemented by call provisioning engine plugins

6.5.5 Event Plugins

Unlike the other plugin types, the event plugins don't have any more operations to implement than the initialize and shutdown operations described in Table 6.1. Instead, they implement their specific functionality by defining one or more event handlers which will react to specific events when these are published at the event bus. How exactly these event handlers work will be discussed later.

6.6 Internal Communication

We also have to consider internal communication between the bootware core and plugins, and possibly also in between plugins. Ideally, every plugin will be able to react to events from the bootware. These events could be triggered by the bootware core or by any plugin, but plugins

should be completely independent from each other. Since a plugin doesn't know about other plugins, it can't listen for events at other plugins directly. The only known constant to a plugin is the bootware core. Therefore we need a communication mechanism which allows for loosely coupled communication between the bootware core and the plugins, where plugins can register their interest for certain events with the core and also publish their own events to the core for other plugins to consume. This essentially describes the publish-subscribe pattern [13].

6.6.1 Publish Subscribe Pattern

The publish-subscribe pattern (PubSub) is a messaging pattern that consists of three types of participant: An event bus (or message broker), publishers, and subscribers. The event bus sits at the center of the communication. It receives messages from publishers and distributes them to all subscribers that have voiced their interest in messages of a certain type by subscribing at the event bus [13]. Using this pattern, we would create an event bus at the bootware core and plugins, as well as other parts of the core, could subscribe at this event bus and also publish messages through this event bus.

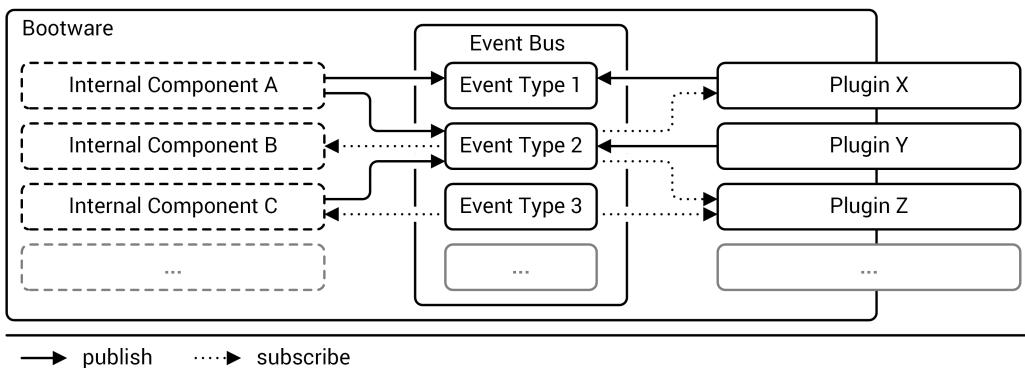


Figure 6.10: Bootware internal communication with PubSub pattern.

6.6.2 Event Types

When using PubSub and events to communicate, it is usually a good idea to not only use one type of event, but many different types. Using different kinds of event allows us to subscribe only to specific events or react differently based on the type of an event. But what if we want to react to each event type in the same way, for example for logging purposes? Now, many

different event types complicate things more. This is where event hierarchies become useful. At the core of an event hierarchy is a single base event. By extending and refining this base event, other, more specific event types can be created, which again can be used as base type for even more specific events. This allows us to create a fine grained hierarchy of events and also enables us to subscribe to particular sub sets of this hierarchy. This makes event handling much easier, since we can now just react to the parent event if we don't need to distinguish between different event types for a particular task.

A second mechanism to differentiate between events is some sort of severity value that each event contains. Many events will be published in an event system, but not all of them might be of the same importance. The majority might be of low value while a few events might be very important. For example, for logging purposes we might not be interested in every event, but only warnings and errors. By adding a severity attribute to the base event type, all events could be categorized in different severity groups and filtered accordingly if needed. As we can see, we might benefit from a well thought-out event hierarchy.

BaseEvent on which all other events are based

CoreEvent published by the bootware core

PluginManagerEvent for loading and unloading plugins

PluginLoadEvent could be info, success, warning, or error

PluginUnloadEvent could be info, success, warning, or error

...

...

PluginEvent published by a plugin

InfrastructurePluginEvent contains further child events defined by plugin

ConnectionPluginEvent contains further child events defined by plugin

PayloadPluginEvent contains further child events defined by plugin

EventPluginEvent contains further child events defined by plugin

...

Figure 6.11: Exemplary event hierarchy.

Figure 6.11 shows an exemplary event hierarchy for the bootware. As we can, every event is based on the BaseEvent, shown at the top. Events can be further divided into core events that are published by the bootware core and plugin events that are published by plugins. Core events contain events from the various core components of the bootware, for example

the plugin manager. The plugin manager events are further divided into events for certain operation that can also have different severity values (i.e. info, success, warning, and error). Plugin events are divided by plugin types. Different plugins can also add further child events to these event types.

6.7 Context

During the bootstrapping process, the bootware has to know certain things to be able do its job. This information can be combined in one central object, which defines the nature of the current request: The context. In this section we will take a closer look at this context object and its content. How exactly the context is implemented is shown in Section 8.4.

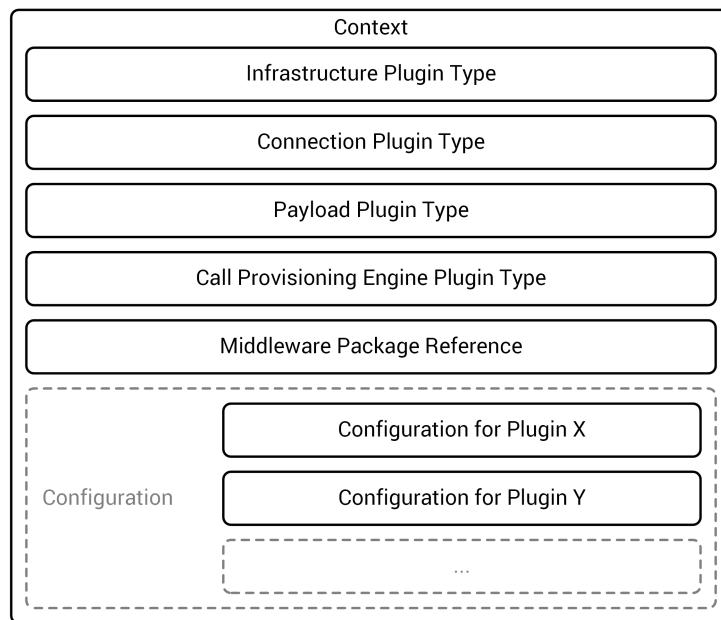


Figure 6.12: Content of the context object.

Figure 6.12 shows the context object and its content. As we can see in the upper half, it defines the plugin types to be used for the current request. The infrastructure plugin type defines, which infrastructure plugin should be used to provision the requested infrastructure. The connection plugin type selects how the bootware should connect to this infrastructure. The payload plugin type defines the payload that should be provisioned on this infrastructure, which will be a provisioning engine in our case. Finally, the call provisioning engine plugin type defines the plugin that should be used to call the provisioning engine. It will use the

middleware package reference, which is also defined in the context, as input to start the provisioning of the workflow middleware. In the bottom half of Figure 6.12 we can see that the context can also contain configuration for different plugins. This is necessary because various plugins might need to be configured properly to be able to fulfill their task. For example, most infrastructure plugins will need some kind of login credentials to authenticate with the infrastructure provider. As another example, when creating a EC2 instance in the Amazon cloud, the user also has to select in which region this instance should be created and which ports should be opened. These and other configuration details can be supplied from the outside with the context. In the future, the context might be extended to hold additional information, but for this thesis, this context will be sufficient.

Now that we have defined what the context will look like, we need to find a way to actually get it to the bootware. There are a few things that we have to keep in mind when doing this. First, these values have to be changeable by the user, so it doesn't make sense to hard-code them into the bootware. Furthermore, the lifetime of the information carried in the context varies quite a bit. The plugin types are only useful for one request execution and are likely to change from request to request, for example if the provisioning manager wants to provision multiple services with different provisioning engines. Therefore, we must provide the plugin types on a per request basis. Since we already decided that we'll be using web services as external communication method, we can send the context containing the plugin types with each request as part of the soap message body. Note that this does not include the event plugins. Event plugins are not changed with each request. They are loaded once when the bootware starts and are unloaded before it stops. Therefore they don't belong into the context. It makes more sense to specify the event plugins that should be loaded in a configuration file that the bootware reads on startup.

Unlike the request plugins, the configuration might not change between requests. Additionally, we have other components calling the bootware who don't know (and maybe shouldn't know) anything about some content of the configuration, like login credentials. While this might change in the future, it would make sense to be able to set the configuration once when starting the bootware, so that it doesn't have to be delivered with each request and so that other components can still use the bootware without also sending a configuration. It should however still be possible to override or update the configuration at a later point. Overriding would allow any request to temporarily use other configuration values if necessary. Updating the configuration at a later point could be useful, for example if the user accidentally provided the wrong credentials at the beginning. Without this functionality, the whole bootware process could fail (even while provisioning the very last service) and would have to be started again from the beginning. This could be avoided by providing the functionality to change configuration even during the bootstrapping process.

For setting the configuration at the beginning and for updating it later during the process, a *setConfiguration* method will be added to the bootware web service. The configuration set by this method will be treated as the default configuration by the bootware. It will be used during the process if no other configuration is provided. If however a request is send with a configuration that also contains values already set in the default configuration, these values will override already existing default values temporarily for this request. This behavior could also be extended to other parts of the context in the future, if necessary.

6.8 Web Service Interface

By now, we know that we will use a web service interface for remote communication. To trigger the basic functionality of the bootware, two operations have to be made public via the web service interface: The deploy and the undeploy operation. In Section 6.7 we also mentioned the *setConfiguration* operation for setting or updating configuration values. We add two additional operations that we also need, the *getActivePayloads* operation and the shutdown operation. Both the local and the remote bootware will have to implement all of these operations, except the *getActivePayloads* operation, which is only needed in the remote bootware.

| Operation | Input | Success Response |
|--------------------------------|---------------------|----------------------|
| deploy | Context | Endpoint References |
| undeploy | Endpoint References | - |
| setConfiguration | Configuration List | - |
| getActivePayloads ² | - | Payload List |
| shutdown | - | Confirmation Message |

Table 6.6: Web service operations provided by the local and remote bootware.

²only in remote bootware

6.8.1 Deploy

The deploy operation is called whenever a new payload (e.g. a provisioning engine, or initially, the remote bootware) should be deployed. As input it takes a context object as described in Section 6.7. If it was able to successfully deploy the requested payload, it responds with an endpoint reference to the payload. If the deployment failed, it responds with an error message.

6.8.2 Undeploy

The undeploy operation is essentially the reversal of the deploy operation. As input it takes an endpoint reference to a payload that should be undeploy. If the undeployment succeeds, it responds with a success message. If it fails, it responds with an error message.

Unlike the deploy operation it doesn't take a context object as input, but the context is still needed for the undeploy operation, since it contains the information about which plugins have to be used. This means that we have to store the context object used during each deploy operation so that we can retrieve it later during the corresponding undeploy operation. This design is intentional and will be described in more detail in Section 6.9.

6.8.3 Set Configuration

The setConfiguration operation is used to transmit or update the default configuration used by plugins. As input it takes a list of configurations that should be saved. If the list provided is empty, the default configuration list saved in the bootware will be emptied. If the list provided is not empty, the default configuration list saved in the bootware will be overwritten by this list. The configuration can still be overwritten on a per request basis if the context send with the request also contains a configuration. If the configuration was updated successfully, it responds with a success message. If the configuration couldn't be updated, it responds with an error message.

6.8.4 Get Active Payloads

The getActivePayloads operation is used by the provisioning manager to check if a provisioning engine he needs already exist. This operation just returns a list of all active payloads. There

is no reason for this operation to be called on the local bootware, so this operation will be implemented in the remote bootware only.

6.8.5 Shutdown

This operation triggers the shutdown of sequence of the bootware. It behaves a little differently in the local and remote bootware. In the local bootware it first calls the shutdown operation of the remote bootware. When the confirmation response from the remote bootware is received, it deprovisions all active payloads that the local bootware deployed (i.e. the remote bootware). In the remote bootware, the shutdown operation first calls a provisioning engine to deprovision the workflow middleware. Once this is done, it deprovisions all active payloads that the remote deployed (i.e. the various provisioning engines), before returning a response.

6.9 Instance Store

The instance store stores information about payloads that were deployed by the bootware in the past and are still active. In Section 6.8 we already mentioned that we need to store some information about active payloads, but we didn't explain why. There are several reasons why this is useful.

One big reason is that we can't guarantee that an undeploy operation will be called for every payload deployed by the bootware, since we might not have control over all components that ultimately call the bootware. We could require that for each deploy call there must eventually be an undeploy call so that everything will be cleaned up in the end, but errors can be made and it is better to have a failsafe in place. In the worst case scenario, failing to call the undeploy operation for some payloads could lead to rogue services remaining active after a bootware execution has stopped without the user realizing it, which could get expensive. Storing enough information allows us to undeploy remaining payloads before shutting down the bootware even if they were never explicitly undeployed. Additionally, a warning could be returned by the bootware to inform the user that some non-bootware component should be modified to explicitly undeploy all services it deployed.

Another reason to store some information about deployed payloads is to simplify the interaction with other components. If we wouldn't store any information and make the bootware stateless, each component using the bootware (e.g. the bootware adapter, the local bootware, and the provisioning manager) would be required to keep track of all payloads it deployed

using the bootware, so that this information can be supplied when it's time to undeploy. This places an extra burden on these components and scatters around the information about deployed payloads. By storing this information in the bootware we simplify the usage of the bootware for other components and concentrate this information in one place. With the `getActivePayloads` operation introduced in Section 6.8 and offered by the remote bootware, other components can always get a list of all active payloads if they need it. This operation also uses the information stored in the instance store.

We should also think about how such a storage mechanism might be different for the local and remote bootware. The local bootware only ever deploys the remote bootware, so here we have to keep track of only one thing. The remote bootware on the other hand might deploy many provisioning engines during an execution. For the local bootware it might be sufficient to store this information in a text file on the local machine where it is executed, whereas the remote bootware might use some sort of persistent storage in the cloud. This would allow it to retrieve this information even after a crash. For this thesis however we will be using simple in memory storage for both the local and remote bootware. Changing that to a more sophisticated storage solution is a possible option for future improvement.

Now that we know why it makes sense to store information about active payloads, we need to discuss what exactly we need to store. We need to store enough information to be able to undeploy an active payload without any further input. For this we need to know: The infrastructure plugin that was used to provision the infrastructure, the connection plugin that was used to connect to it, the payload plugin that was used to deploy the active payload, and login credentials for the remote environment if necessary. This is all contained in the context object that we used in the first place to deploy the payload, so we will just store the whole context object. Since we also use this storage for the undeploy operation, where we get an endpoint reference as input, we have to store it in such a way that we can map a particular context object to the provided endpoint reference.

6.10 Shutdown Trigger

One thing that we haven't mentioned yet is how the bootware will be shut down. The bootware can't just stop. It has to make sure that all payloads and all the infrastructure it has provisioned is removed before it shuts down itself. But how does the bootware know when it's time to start this procedure? After all, this depends on the workflow middleware. The shutdown process should start when the workflow middleware is finished with the workflow execution, so the bootware has to be informed of this somehow.

One possibility is to trigger the shutdown procedure from the bootware plugin in the modeler. If the bootware adapter can access this information through the modeler, it can call the shutdown operation of the local bootware, which will in turn call the shutdown operation of the remote bootware, which will eventually lead to the removal of all remote components. If this is possible using a particular modeler depends on the modeler and the integration possibilities for the bootware adapter.

There is a second possibility that can be used instead of the first one. We already introduced the event plugin type, which can also trigger events in the bootware, in particular the shutdown event. An event plugin could be created that somehow communicates with the workflow middleware to receive notice when the execution is finish. For example, in the SimTech SWfMS, the workflow engine publishes event into a message queue. An event plugin could be created that subscribes to this messages queue and reacts to a particular event by triggering the shutdown event inside the bootware. This plugin would then be loaded into the local bootware and would trigger the shutdown procedure, which would in turn call the shutdown operation of the remote bootware as before.

6.11 Execution Flow

Until now we have established how the bootware can be called from outside components using a web service interface and a context to start the bootstrapping process. We also established that big parts of this process will be implemented as plugins. Now it's time to take a look at the actual internal structure of the bootware. What follows is a step by step description of the whole bootstrapping process.

Figure 6.13 shows a graph that represents the major steps during the bootware execution in the local bootware as flow diagram. The bootstrapping process is started by executing the local bootware, which is represented by the start state in the top left corner of Figure 6.13. From there, the bootware first does some initializations. If those fail for some reason, the cleanup code will be executed before the local bootware execution is ended, as can be seen on the top right corner of Figure 6.13. In most cases however, the initialization should succeed. Then, the local bootware will transition to the next state, where it tries to load the event plugins.

The event plugins are loaded once at the beginning of the local bootware execution, since they will not change at a per request basis (like the other plugins). If loading one of these plugins fails, the local bootware will try to unload already loaded plugins before continuing to the cleanup state. If the plugins are loaded successfully, the local bootware transitions into the wait state, shown in the top center of Figure 6.13.

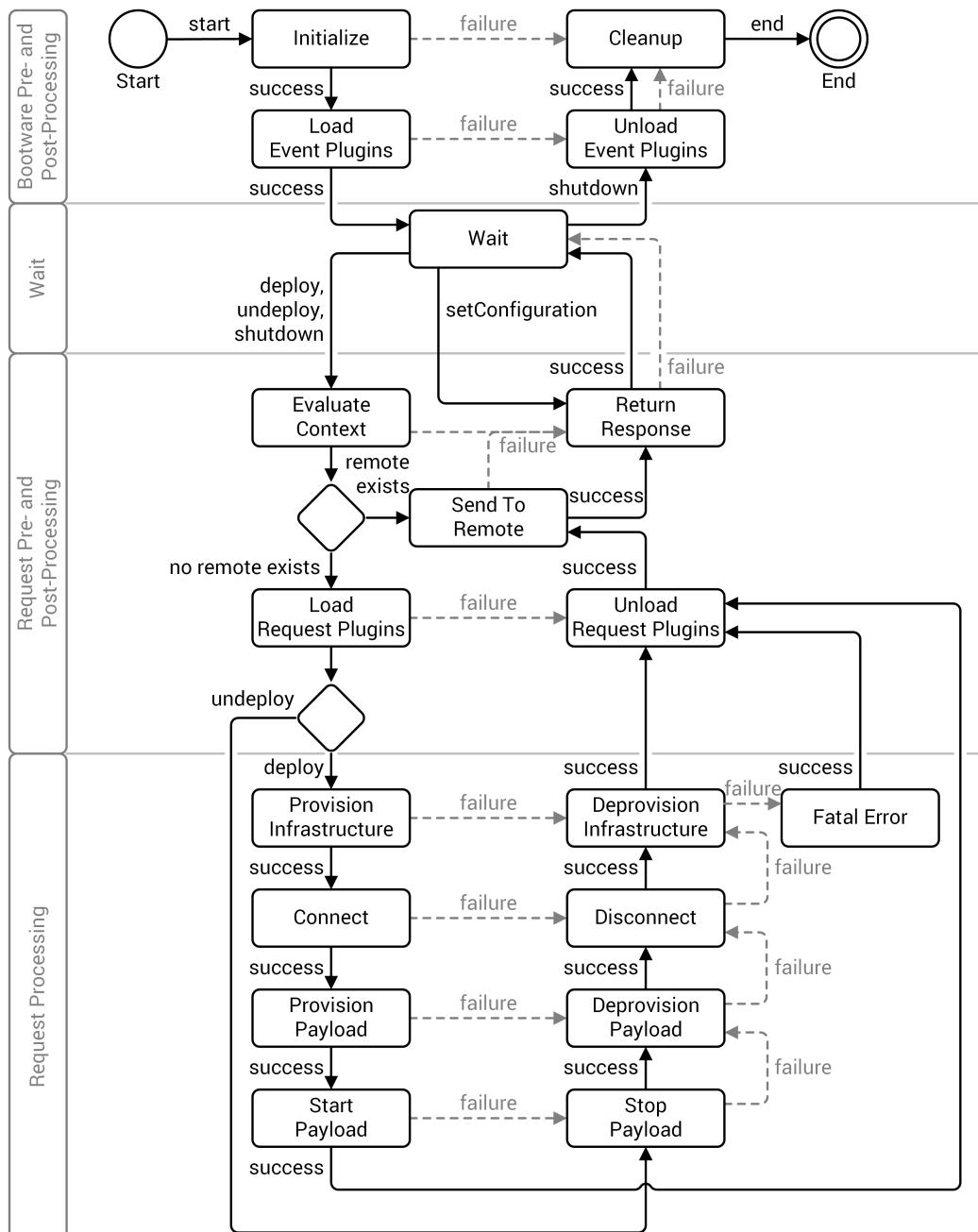


Figure 6.13: Execution flow in the local bootware.

Once the local bootware is in the wait state it is ready to receive requests from the outside. If a shutdown event is received in this state, the local bootware will first tell the remote bootware to undeploy all active payloads. Next, the local bootware will undeploy the remote bootware by running through the undeploy process shown on the bottom left with the appropriate plugins. Then, it will shut itself down by first unloading the event plugins and then running the cleanup code. This is the only normal way to shut down the local bootware. We only hint at the setConfiguration request here, since it is so simple that it could also be handled in the wait state. Deploy and undeploy requests however are more complicated. If such a request is received in the wait state, the local bootware transitions to the next state, where it reads the request context.

The request context contains all the information necessary to fulfill the request, as described in Section 6.7. If the context can not be read, the local bootware returns a response containing an error message before returning into the wait state. If the context is read successfully the local bootware tries to send the request on to the remote bootware, as shown in the middle of Figure 6.13. For this to work, the remote bootware has to exist in the requested remote environment, which won't be the case during the first execution. Therefore, the local bootware first has to provision the remote bootware in the requested remote environment and so it transitions to the load request plugins state.

In the load request plugins state the plugins specified in the context are loaded. If this fails, the local bootware tries to unload already loaded plugins before returning an error response and transitioning to the wait state. If the plugins are loaded successfully, the local bootware now starts either the deploy process or the undeploy process, shown at the bottom of Figure 6.13, depending on the type of the request.

If the request was a deploy request, the local bootware will now execute the steps shown in the bottom left of Figure 6.13 one after another, which include the deploy, connect, and start operations of the infrastructure, connection, and payload plugins. If one of those operations fails the local bootware transitions over to the corresponding undeploy operation and works its way backwards to undo all operations that were already executed. This process is the same as the undeploy process, shown on the bottom right of Figure 6.13, which is triggered by an undeploy request.

If the stop payload, deprovision payload, or disconnect states fail, the local bootware just continues with the next undeploy state, since these operations are not considered critical. However, if the deprovision infrastructure state fails, the local bootware transitions to a fatal error state, shown at the right of Figure 6.13, since this step is considered critical. This state failing could mean that resources are still active in the cloud and human interaction is necessary to remove them to stop further costs from incurring. The fatal error state is

responsible for taking special actions to remedy this situation.

The successful, as well as the unsuccessful execution of either the deploy or the undeploy process all finish in the unload request plugin state, where the plugins that were needed for this particular request are unloaded. If everything went as planned, a remote bootware should now be running in the desired cloud environment and the local bootware can now pass on the request to this remote bootware, as shown in the center of Figure 6.13. The local bootware will wait in this state until it receives a response from the remote bootware.

Now, we move our attention to the remote bootware, where the requests continues to be processed. Figure 6.14 shows the execution flow of the remote bootware. As we can see, it is largely identical to the local bootware, at least at the moment. The send to remote state is gone, since we don't need this in the remote bootware. Instead, as the bottom of Figure 6.14 shows, the provision and deprovision middleware steps were added. The remote bootware also supports the getActivePayloads request. Other than that, the local and remote processes are the same.

Like the local bootware, the remote bootware went through the initialization steps shown at the top of Figure 6.14 when it was started by the local bootware. It then waited in the wait state for a request. Now, it receives the request from the local bootware, reads the context, loads the request plugins and executes the deploy operation. This should result in a provisioning engine being started by the payload plugin. After that, the remote bootware enters the new provision middleware state at the bottom left of Figure 6.14, which will use the just started provisioning engine to deploy the workflow middleware by executing the call provisioning engine plugin. Once the middleware is running, the remote bootware is finished with this request and returns the endpoint references of the middleware in the response to the local bootware, before returning into the wait state.

This brings us back to Figure 6.13, where the local bootware has now received the answer from the remote bootware in the send to remote state. Now, the local bootware can finish its request by sending back a response to the bootware adapter, before returning to the wait state. The local bootware is now done until it's time to undeploy the remote bootware. Meanwhile, the bootware adapter starts the workflow execution on the middleware, during which multiple calls from the provisioning manager to the remote bootware will occur, which will each time trigger the deploy or undeploy process shown at the bottom, or the getActivePayloads operation only hinted at in Figure 6.14.

As Figure 6.13, Figure 6.14 and the description above show, this is quite a complicated process with many conditional transition. Using traditional programming methods like if/else blocks to implement this process would lead to a rather unwieldy and complicated construct with lots of nested if/else block. Therefore, it could be advantageous to use other methods that

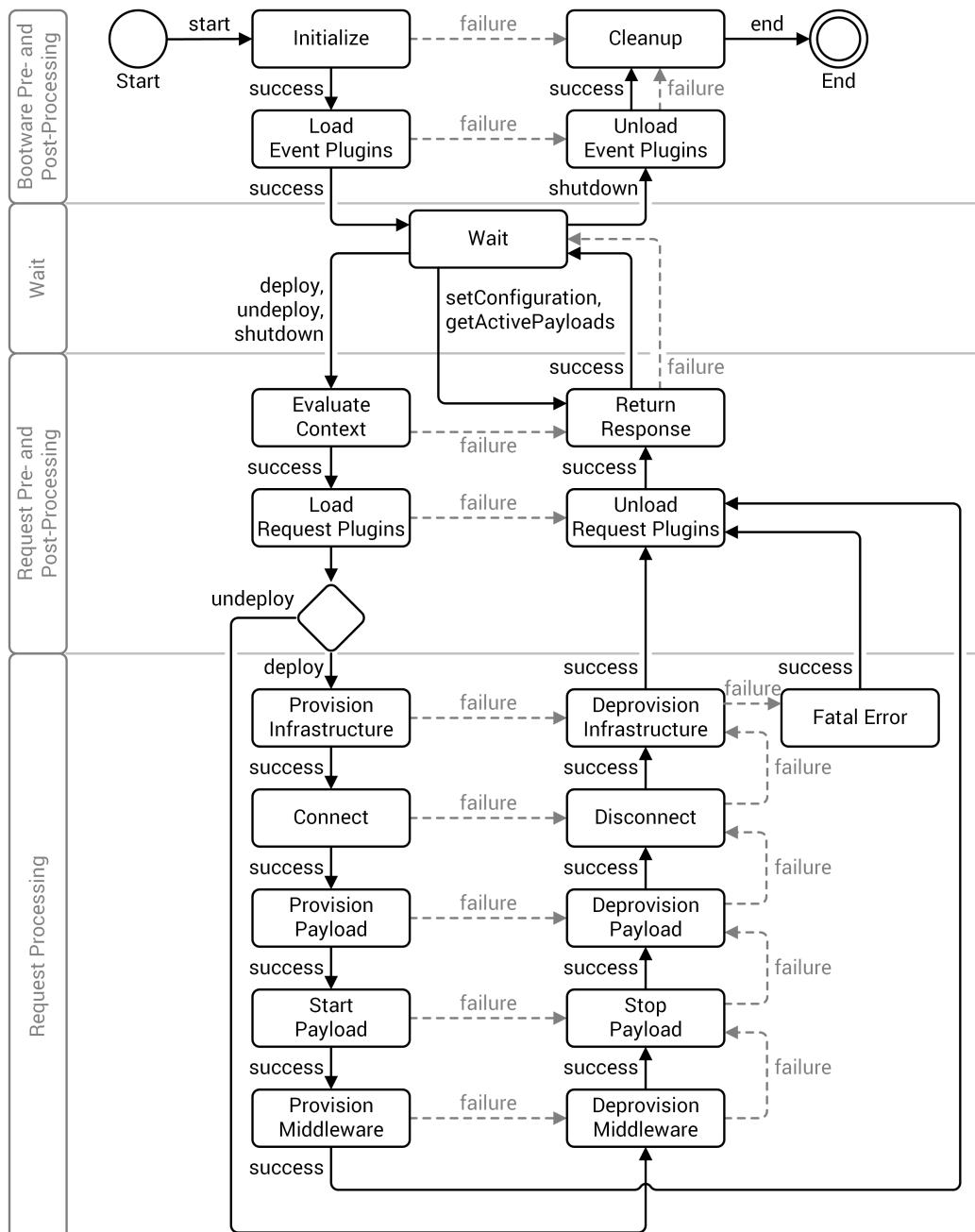


Figure 6.14: Execution flow in the remote bootware.

are more fitting for this process. Since we already described the process as a directed graph with states and transition, it would be ideal if we could take this whole graph and use it in the bootware. Fortunately, this is possible by implementing the process using a finite state machine.

6.11.1 Finite State Machine

In theoretical computer science, a Finite State Machine (FSM) is a formal, abstract model of computation that “consisting of a set of states, a start state, an input alphabet, and a transition function that maps input symbols and current states to a next state. Computation begins in the start state with an input string. It changes to new states depending on the transition function” [5]. In this context, a state is the “condition of a finite state machine [...] at a certain time. Informally, the content of memory” [6]. The start state is therefore the initial condition of a FSM. The alphabet is a “set of all possible symbols in an application. For instance, input characters used by a finite state machine, letters making up strings in a language, or symbols in a pattern element. In some cases, an alphabet may be infinite” [3]. The transition function is a “function of the current state and input giving the next state of a finite state machine” [7]. FSMs can further be distinguished in deterministic and non-deterministic FSMs. A deterministic FSM has at most one transition for each symbol and state, whereas a non-deterministic FSM can have non, one, or more transitions per symbol and state [4].

Aside from its uses in theoretical computer science, FSMs also have practical applications in digital circuits, software applications, or as lexers in programming language compilers. We are only interested in the use of FSMs for building software, so we can redefine what a FSM means for our case. We want to use a FSM as an abstract machine that is defined by a finite list of states and some conditions that trigger transitions between those states. Unlike a traditional FSM, we will not consume symbols from a set alphabet that will trigger state transitions. We want the state transitions to be triggered by events that we can emit at any time, so we want an event-driven FSM. The machine is in only one state at a time, its current state. At the start of the machine execution, it will be in the start state. From there, it can transition from one state to another when certain events are triggered, until it finally reaches an end state. When it enters a state, it executes a function associated with this state. The result of the execution of this function determines to which state the FSM will transition next. We will talk more about the actual implementation with FSMs in Chapter 8.

6.12 Final Bootware Architecture

In Figure 6.15 we present the final architecture of the bootware in context with a SWfMS. New components are marked black and include the local and remote bootware, their plugins, and the bootware adapter. Old components that existed previously are shown in white.

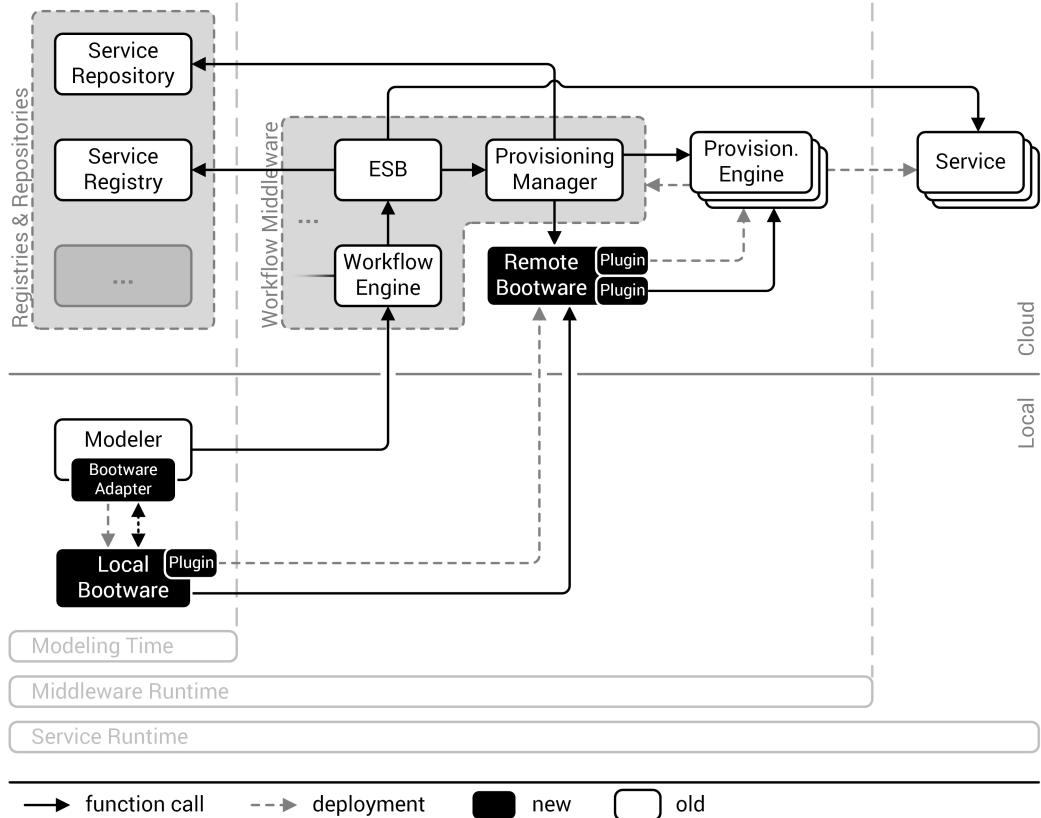


Figure 6.15: The final architecture of the bootware.

Figure 6.16 and Figure 6.17 show the final architecture of the local and remote bootware. They only differ in some small details, but this might change in the future. At the bottom we can see some exemplary event plugins. These are loaded at the beginning of the bootware execution by the plugin manager, shown on the left of both figures. For demonstrations purposes, both figures shows a wider range of possible event plugins. All these plugins provide some sort of input and/or output mechanism for the bootware. A command-line interface (CLI) plugin, as shown in Figure 6.16, could be used to make the bootware operations accessible via a command-line interface. An event logger plugin could be used to write all bootware events to a log file. We can also imagine an event queue plugin that pushes all bootware events

into some message queue at the remote bootware, so that they can be consumed by other components, like the local bootware. Finally, an undeploy trigger plugin in the local bootware, as shown in Figure 6.16, could trigger the undeployment of the bootware and all running payloads by listening for a specific message at the workflow middleware. Besides the event plugins there is always the web service interface, shown at the bottom right of both figures, which provides the standard way to interact with the bootware.

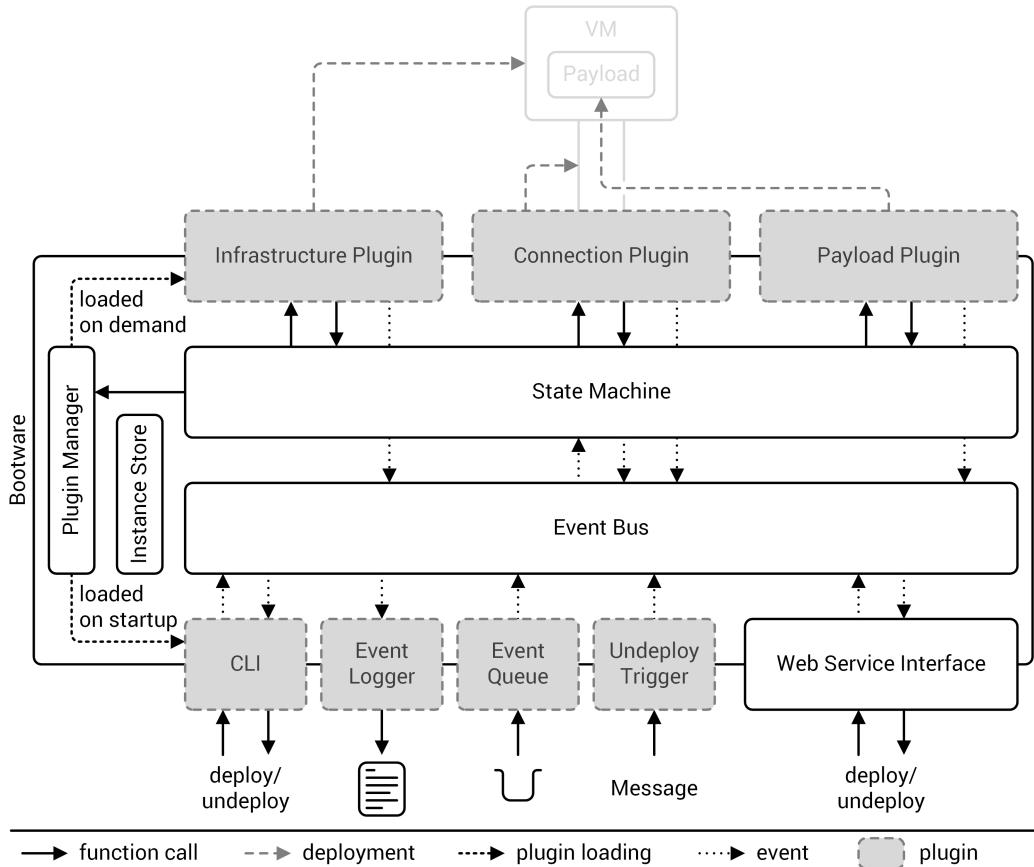


Figure 6.16: The final architecture of the local bootware component.

All event plugins and the web service interface work by implementing event handlers for certain events published at the event bus, or by publishing events to the event bus themselves. As we can see in the center of both figures, the event bus and the state machine form the core of the bootware. The event bus is responsible for distributing events between the various plugins and the state machine. The state machine implements the entire bootstrapping process, as described earlier in Section 6.11. At certain points during the bootstrapping process, operations are delegated to the plugin manager to load plugins, and to the infrastructure, connection, payload, and call provisioning engine plugins, shown at the top of both figures.

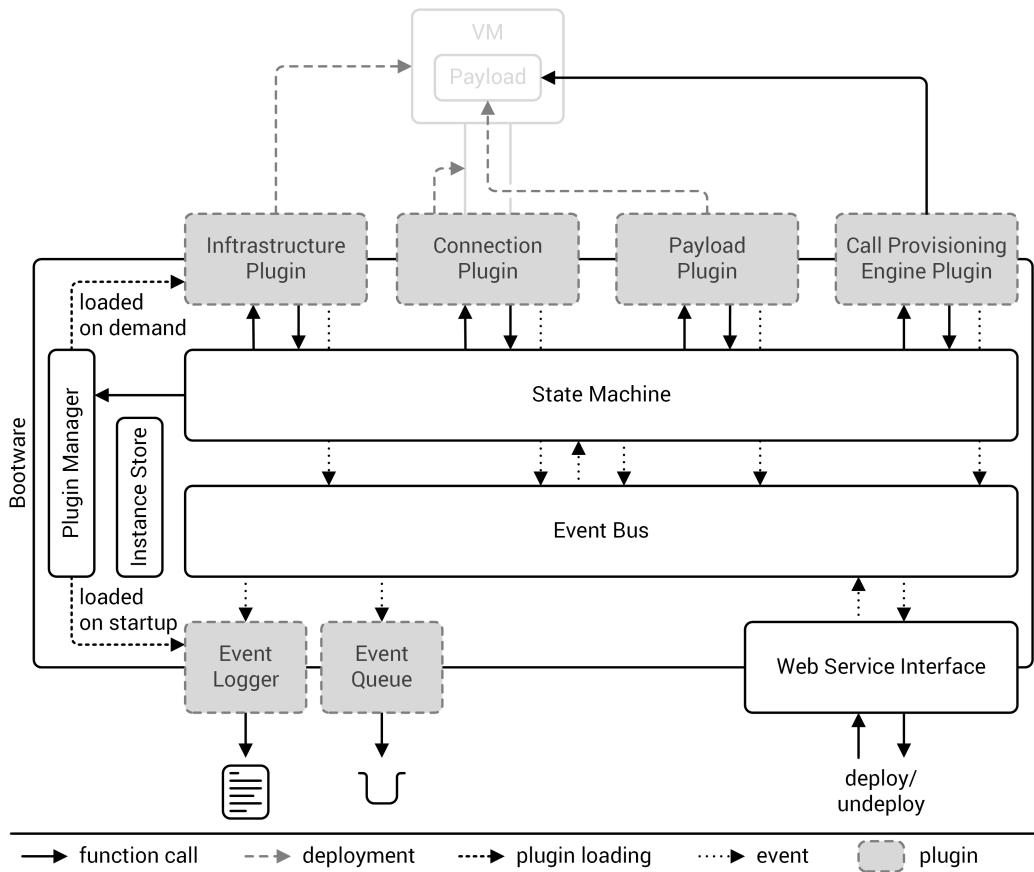


Figure 6.17: The final architecture of the remote bootware component.

The infrastructure, connection, and payload plugins implement the actual bootstrapping operations. At the top, both figures show an exemplary result of these bootstrapping operations. In this particular case, the infrastructure plugin started a VM, to which the connection plugin set up a communication channel. The payload plugin then used this communication channel to provision the payload inside the VM. The provisioning engine plugin is only available in the remote bootware and allows it to call a provisioning engine with the details necessary to provision the workflow middleware. This is shown in Figure 6.17 as an additional function call from the call provisioning engine plugin to the previously deployed payload. During the bootstrapping procedure, events are sent from all these plugins back to the event bus to be delivered to the loaded event plugins. As we can now see, the local and the remote bootware are quite similar, but differ in enough ways that a cloned architecture, as described in Section 6.1, might not be the best choice, especially since both components might drift further apart in their functionality in the future. Therefore we decide to not alter our original decision to go with a 2-tiered architecture.

7 Bootstrapping Process

This chapter describes the bootstrapping process in its entirety. The entire process can be divided into three phases. During the bootstrapping phase, the local and remote bootware components are started and provision a provisioning engine, which in turn provisions the workflow middleware. Once the workflow middleware is ready, the second phase starts, which is the workflow execution phase. During this phase, the remote bootware might be called multiple times to deploy or undeploy new provisioning engines. The third and final phase, the shutdown phase, begins when the workflow execution is finished. In this phase, all remaining services, provisioning engines, the workflow middleware, the remote and the local bootware, as well as all the underlying infrastructure are deprovisioned. In Figure 7.1, we can see the whole process with numerated steps. We will go through Figure 7.1 step by step in the following paragraphs to get a better understanding of the whole bootstrapping process.

At the beginning, a user starts the Modeler, which includes the bootware adapter, as seen on the bottom left of Figure 7.1. If they haven't done so already, they configure the bootware adapter with their cloud login credentials to be used during the bootware process and other parameters that might be needed. They also select, which event plugins the bootware should load. They then use the Modeler to create a workflow as usual. Once the workflow is finished and ready to be executed, they click the start button as usual. This marks the beginning of the bootstrapping phase. The bootware adapter has hooked into the start process and takes over by starting the local bootware (step 1).

Once the local bootware is up and running, the bootware adapter calls it with the context the user provided (step 2). The local bootware first checks, if a remote bootware already exists in the requested remote environment. If not, the local bootware provisions a remote bootware using the information provided in the context (step 3). Once the remote bootware is deployed, it is called by the local bootware with a deploy request for the provisioning engine that will be used to deploy the workflow middleware (step 4). The remote bootware deploys the requested provisioning engine using the information provided in the context (step 5). Once the provisioning engine is up and running, the remote bootware calls the provisioning engine (step 6) and tells it to deploy the workflow middleware (step 7). Once the workflow middleware is up and running, the provisioning engine returns the endpoint references of the workflow

7 Bootstrapping Process

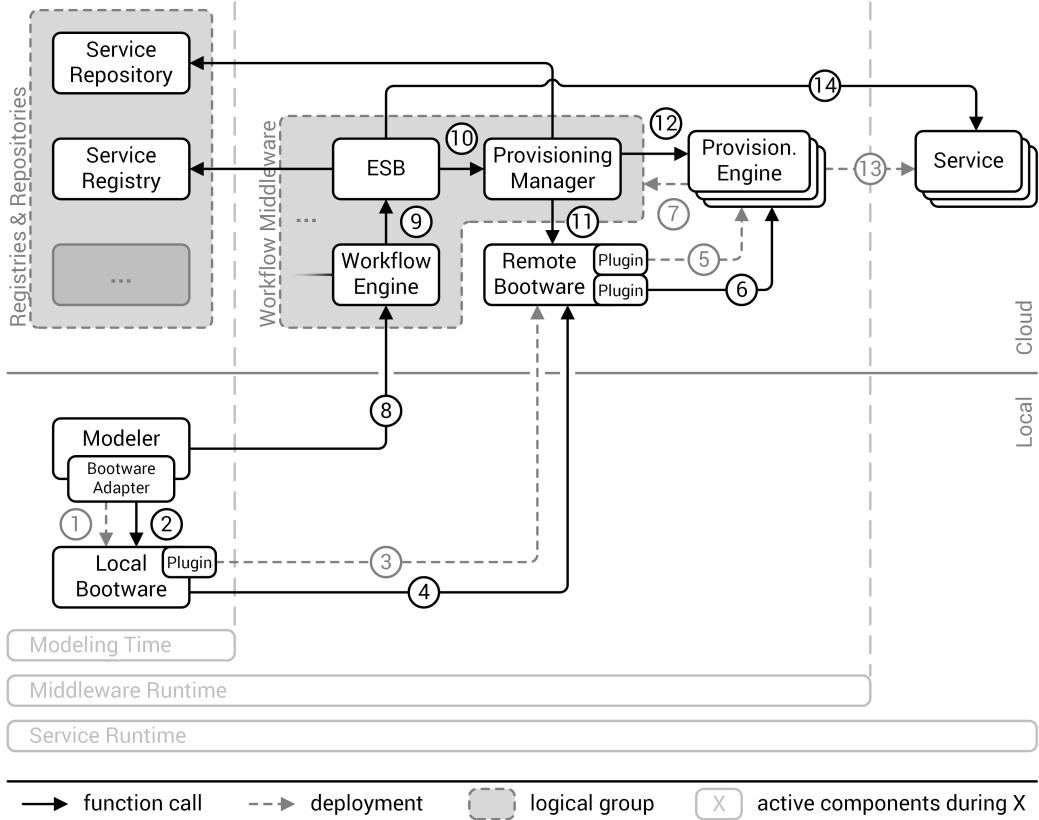


Figure 7.1: The step-by-step bootware process.

middleware to the remote bootware, which in turn returns it to the local bootware, which returns it to the bootware adapter. The bootware adapter uses those end point references to link the modeler to the workflow middleware. This is the end of the bootstrapping phase. Now begins the workflow execution phase.

Once linked, the modeler deploys the workflow on the workflow middleware as usual and starts its execution (step 8). The workflow middleware now executes the workflow, during which it might encounter a point where it has to call a remote service. The remote service call is passed on to the ESB (step 9), which checks if the service is already reachable. If it is, execution continues as usual. If not, the ESB tells the provisioning manager to provision the requested service (step 10). The provisioning manager checks, if the provisioning engine needed to provision the requested service is already available. If it isn't, the provisioning manager calls the remote bootware with a request to provision the required provisioning engine (step 11). The remote bootware provisions the provisioning engine using the information from the request and the user context (step 5). Once the provisioning engine is up and running, the

7 Bootstrapping Process

remote bootware returns the endpoint reference of the provisioning engine to the provisioning manager. The provisioning manager now calls the provisioning engine (step 12) and tells it to provision the required service (step 13). Once the service is available, the provisioning engine returns its endpoint reference to the provisioning manager, who in turn returns it to the ESB. The ESB can now call the service (step 14) and use the service response to continue with the workflow execution. The workflow execution now continues in this fashion, spawning new provisioning engines and services through the provisioning manager and the remote bootware along the way (repeating steps 9, 10, 11, 5, 12, 13 and 14). At some point, the workflow will be finished. This marks the end of the workflow execution phase and the start of the shutdown phase.

If it hasn't done so already, the provisioning manager calls all relevant provisioning engines to undeploy any services that might still be running (step 12, 13). Once all services are undeployed, the work of the workflow middleware is finished. The bootware is listening at the workflow middleware for this event and triggers the undeploy process once it happens. First, the remote bootware calls the provisioning engine that was used to provision the workflow middleware (step 6) and tells it to undeploy the workflow middleware (step 7). The provisioning engine returns the success to the remote bootware. Next, the remote bootware undeploys all provisioning engines that might still be running (step 5). Once all provisioning engines are gone, the remote bootware returns the success to the local bootware. The local bootware removes the remote bootware (step 3) and returns the success to the bootware adapter. At this point, no remote components should be running anymore. The local bootware now shuts down itself, which completes the whole process.

Figure 7.2 shows the bootstrapping phase as sequence diagram, which displays the interaction between the components arranged by time from top to bottom. The lifetime of a particular component is represented by a dashed line running from the top to the bottom. If an activity box is displayed over the line, the component is active at this moment in time. Activity is usually triggered by receiving a call from another component and ended by returning a response to this call. Calls are represented by arrows between activity boxes. They can be further distinguished between synchronous and asynchronous calls, depending on the form of the arrow head. A response is displayed as a dashed arrow between activity boxes. The end of the lifetime of a component (i.e. when it is shutdown) is marked by a cross that ends the lifetime line.

In Figure 7.2 we can clearly see how one component triggers the next one during the bootstrapping phase. Starting at the top left, the deploy action starts an escalating process, where one component starts the next, beginning with the modeler starting the bootware adapter. The bootware adapter then starts the local bootware and sends a deploy request. The local bootware deploys and starts the remote bootware and forwards the deploy request. The

7 Bootstrapping Process

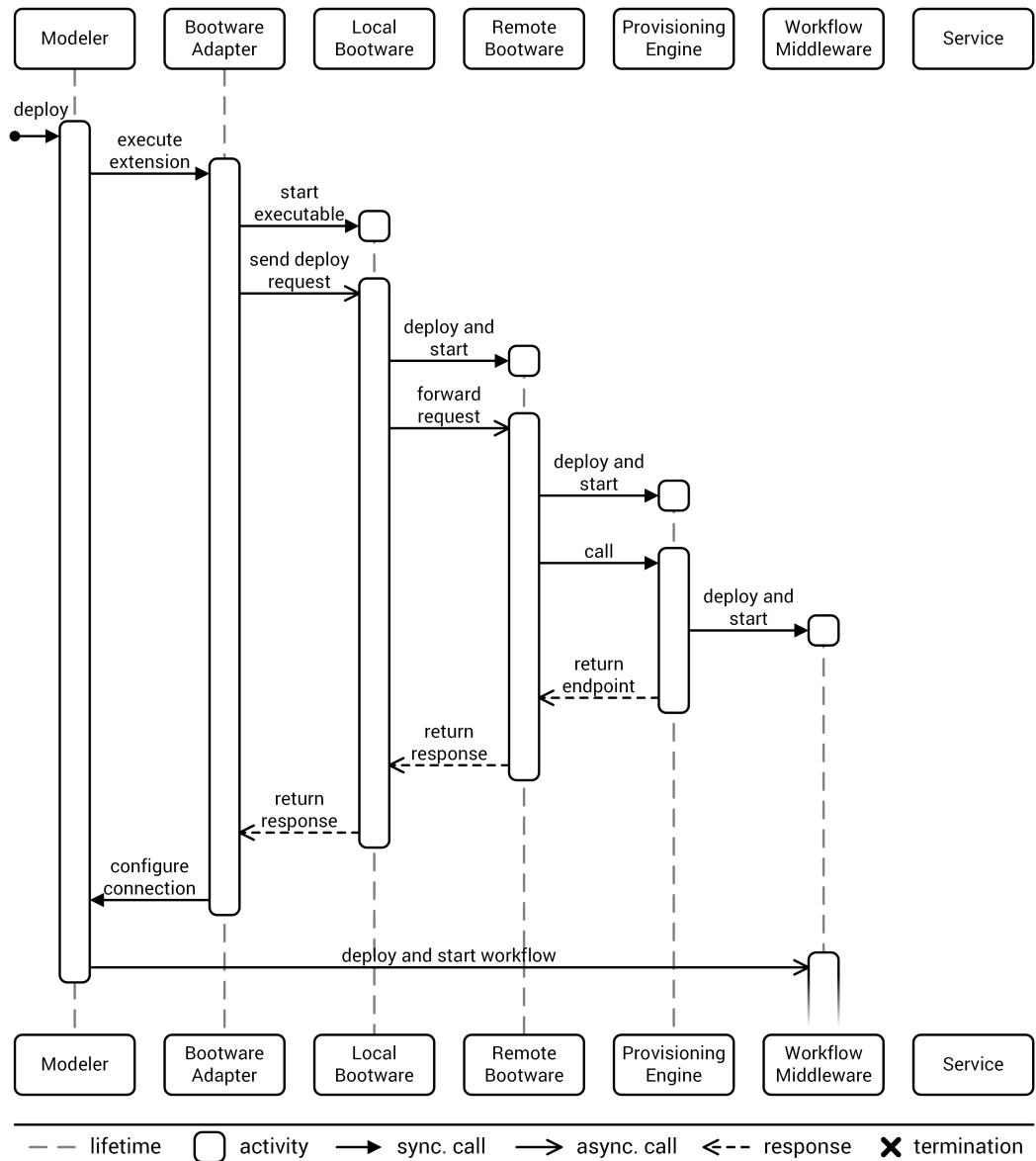


Figure 7.2: Sequence diagram of the bootstrapping phase.

remote bootware deploys and starts a provisioning engine, which it then calls to provision the workflow middleware. Once the workflow middleware is running, every component returns a response to the component who called it, which ends when the bootware adapter receives a response from the local bootware. This response contains the endpoint references to the workflow middleware, which the bootware adapter uses to configure the connection between the modeler and the workflow middleware. The modeler can now deploy and start the workflow on the workflow middleware, which concludes the bootstrapping phase.

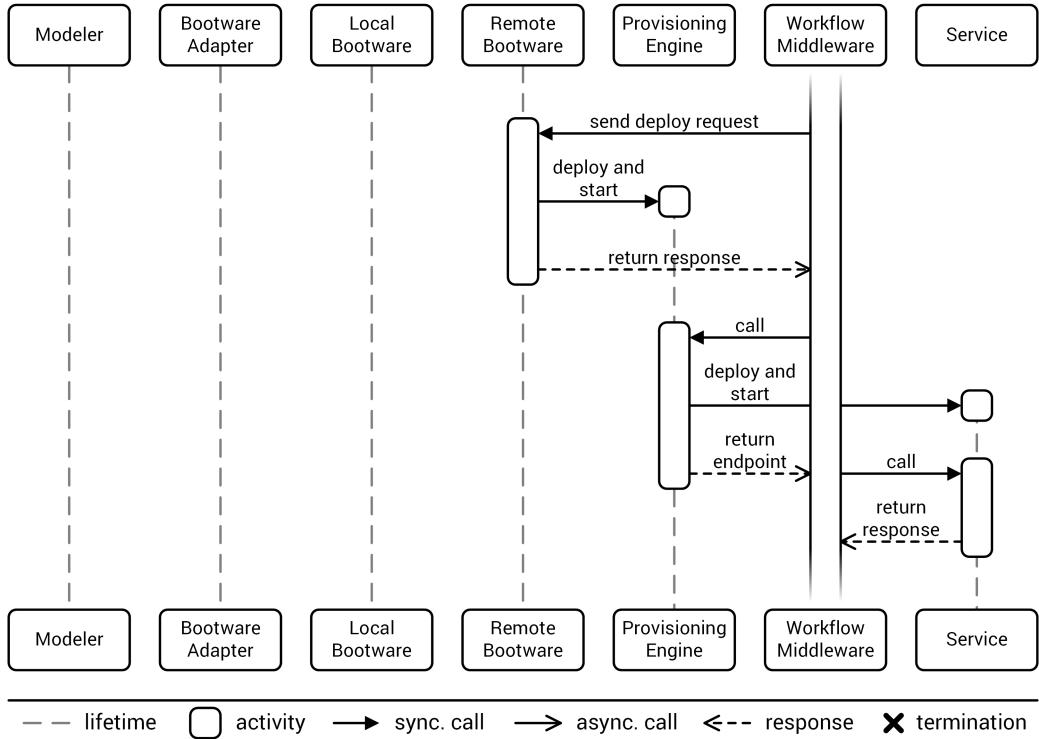


Figure 7.3: Sequence diagram of the workflow execution phase.

In the workflow execution phase, which is also depicted as a sequence diagram in Figure 7.3, the workflow middleware might now call external services. If these services don't exist already, the workflow middleware has to provision them first (via the provisioning manager). To provision a service, a particular provisioning engine is needed, which also might not exist yet. In this case, a deploy request is sent from the workflow middleware (i.e. the provisioning manager) to the remote bootware, which then deploys and starts the requested provisioning engine. Once the particular provisioning engine exists, the workflow middleware calls it to deploy the service it wants to execute. This process might be repeated multiple times during the whole workflow execution.

7 Bootstrapping Process

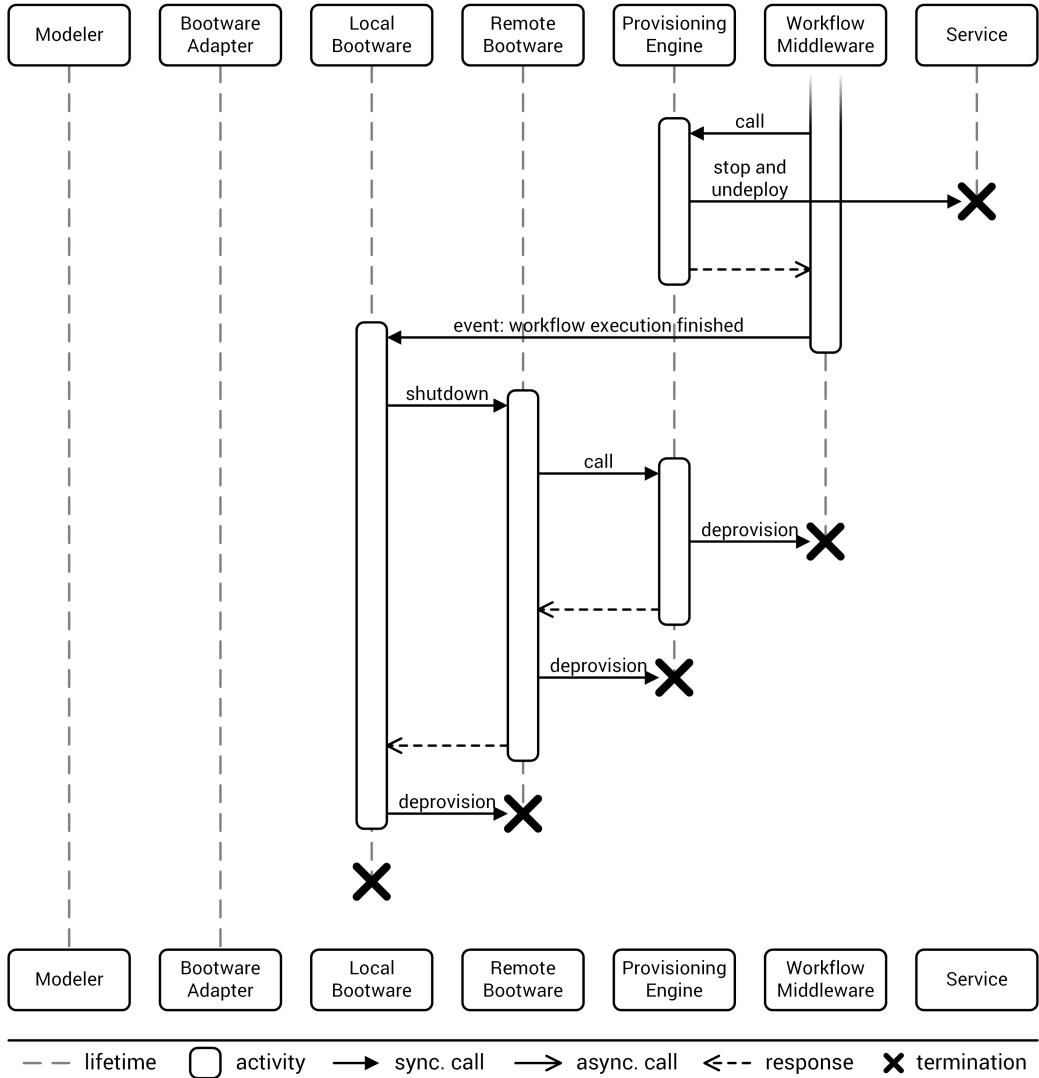


Figure 7.4: Sequence diagram of the shutdown phase.

The shutdown phase begins once the workflow execution is finished. As we can see in Figure 7.4, the workflow might need to stop and undeploy remaining services by calling the particular provisioning engines via the provisioning manager. Once all services are removed, the workflow execution is truly finished and an event marking this state is emitted. The local bootware has been listening for this event through one of its event plugins and triggers the removal of the remaining components by first calling the shutdown operation of the remote bootware. The remote bootware calls a provisioning engine to deprovision the workflow middleware, before deprovisioning all remaining provisioning engines itself. Once this is done,

7 Bootstrapping Process

a response is send to the local bootware, which can now deprovision the remote bootware, before shutting down itself. This concludes the shutdown phase and the whole bootware process.

8 Implementation

Until now we have described the bootware in a generic context, since it should work with various different SWfMSs. But for the implementation we will have to work with a specific system, which in our case is the SimTech SWfMS. Figure 8.1 shows the bootware being used together with the SimTech SWfMS. It also shows the components as one of three types: specific, generic, and adapted. The specific components, shown in black, are those components that belong to a specific SWfMS. In our case these are the SimTech Modeler at the bottom left and the SimTech ODE (and other components that were omitted in this figure) in the center. On the other hand we have the generic components, shown in white. These are components that are build to be generic and can be used in all kinds of environments. In our case these are the local and remote bootwares and their plugins, as well as the provisioning manager and the ESB (here Apache Service Mix) and various repositories and registries. The specific and the generic components have to work together, but there should be no need to make huge modifications to either one to do so. Therefore, we need adapter components in some places, which are shown in gray in Figure 8.1. They are responsible for gluing together specific and generic components where necessary and should be the only components that have to be modified or created from scratch to fit to a specific environment. In our case this is the bootware plugin, an implementation of the bootware adapter described in Section 6.2, loaded in the SimTech Modeler on the bottom left. There also is an adapter component between the SimTech ODE and Apache Service Mix, which is not shown here.

For the implementation of this diploma thesis we will have to create the generic local and remote bootware components and their plugins, as well as the bootware plugin, which will be specific to the SimTech Modeler. In the rest of the chapter we present details on the implementation of the bootware components. First we describe the implementation of the bootware plugin. Next, we select specific frameworks and libraries that allow us to implement the architecture we developed in Chapter 6. Then we present detailed descriptions of the implementation of some parts of the local and remote bootware and some plugins.

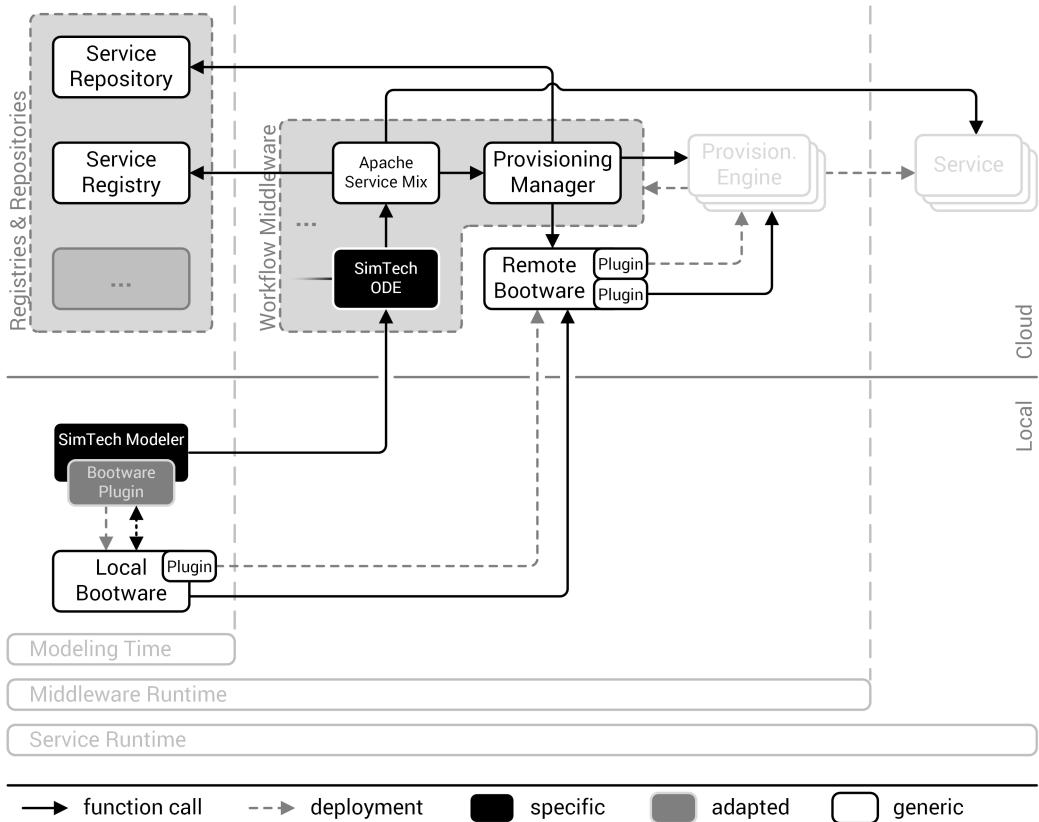


Figure 8.1: Specific and generic components and adapters.

8.1 Modeler Integration

In this section we describe the integration between the SimTech SWfMS and the bootware. Currently, what happens is that if a workflow is ready and should be executed, the user clicks on a button in the SimTech Modeler and the workflow is deployed and executed on the SimTech SWfMS. Now we have to find a way to integrate the bootware into this process. We described this as a generic bootware adapter in Section 6.2, but now we need an actual implementation of this adapter, which will be specific to the SimTech Modeler. The button is realized by an Eclipse plugin that adds SimTech specific functionality to the Modeler (which is based on Eclipse). We therefore also have to create some kind of Eclipse plugin to hook into this process. We call it the bootware plugin. There are two scenarios how we could go about this.

We could extend the existing plugin with the functionality that we need for the bootware. In

this case, we would always load the bootware extensions in the Modeler, even if we don't use the bootware at all. We could also use a feature called extension points. Eclipse plugins can declare extensions points, which allow other plugins to extend or customize parts of the plugin¹. We could define an extension point in the already existing eclipse plugin and create a second plugin which implements this extension point. This way we can separate the bootware functionality from the other SimTech extensions and keep the changes to the existing plugin to a minimum. If a user doesn't need the bootware functionality, they don't have to load the bootware plugin and the SimTech plugin will continue to function as before.

The second scenario looks preferable to the first one, so this is what we are going to do. We modify the already existing Eclipse plugin with an extension point that is triggered at the beginning of the existing deployment process. If the bootware plugin is loaded into the Modeler, it will implement this extension point and set up the SimTech SWfMS before the already existing deployment code continues. If it is not loaded, nothing new will happen and the existing deployment code will be executed like before. The bootware plugin can also add additional extension to the modeler, for example a configuration dialog for setting up the context or a view that shows progress messages from the bootstrapping process.

8.2 Bootware Core Library

We have seen in Section 6.11 and Section 6.12 that the local and remote bootware have some common functionality. It would make sense to implement these components in such a way that they can share this common functionality. This would avoid code duplication and make changes to common functionality easier. Therefore we introduce the bootware core library, which will encapsulate the common functionality of both bootware components.

Since we are using Java for the implementation, the core library will be a *.jar* file containing common classes that will be imported by the local and remote bootware implementations and also by plugin implementations. Figure 8.2 shows a schematic view of the bootware core library and how its classes are used by various components. We can see that the library includes an abstract FSM class, which is used by both the local and the remote bootware implementation. The abstract FSM class defines common state machine functionality that is used by both bootware components. This includes function definitions for the shared states shown in Figure 6.13 and Figure 6.14. This way, the local and remote bootware can import shared states from the library and only have to define their custom states (e.g. the provision middleware states in the remote bootware or the send to remote state in the local bootware)

¹http://wiki.eclipse.org/FAQ_What_are_extensions_and_extension_points%3F

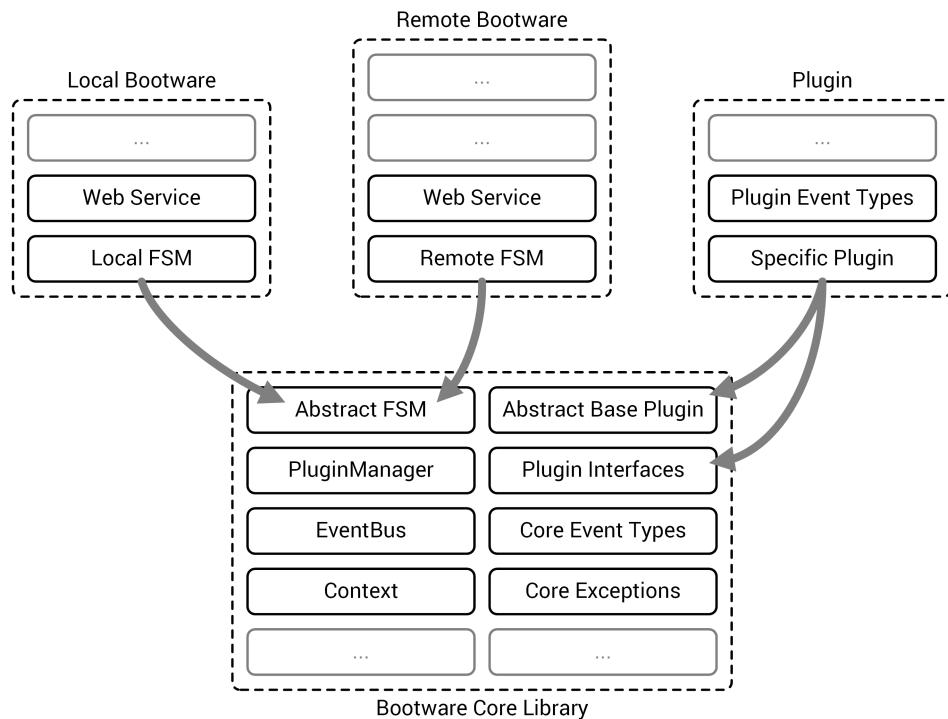


Figure 8.2: The bootware core library and exemplary usage.

and the state transitions. They can also overwrite the states imported from the library if this is necessary.

The library also includes an abstract base plugin class, which implements some functionality that is common to all plugin. Actual plugin implementations can extend this base plugin class to inherit this common functionality. They also have to implement one of the plugin interfaces defined in the bootware core library, so for example, an infrastructure plugin has to implement the infrastructure plugin interface.

Aside from the code imported from the bootware core library, the components using the library are free to add various other code to their implementation. This way, the remote bootware could implement some extra functionality not needed in the local bootware, or a plugin could define its own event types.

8.3 Selecting Frameworks and Libraries

Before we can begin with the actual implementation of the local and remote bootware, we have to decide on which frameworks and libraries we will use to implement the requested functionality. In this section we present the frameworks and libraries we chose and the reasoning behind it. We begin with plugin frameworks, followed by PubSub and FSM libraries.

8.3.1 Plugin Frameworks

All the frameworks that we compare here offer the basic functionality that we need to extend the core bootware components, i.e. the developer defines interfaces that then are implemented by one or more plugins. These plugins are compiled separately from the main component and are then packaged in *.jar* files for distribution. These packages are loaded during runtime and provide the implementation for the specific interface they implement. There are however some advanced functional differences and some non-functional differences that will be considered here.

Dynamic loading allows us to load and replace plugins during runtime, without completely restarting the application. This is an important feature, since it is possible that the bootware has to use many different plugins during its lifetime. For example, this would be the case when several services have to be provisioned, each with different provisioning engines. In this case, the bootware has to load the appropriate plugins for every provisioning engine to be able to fulfill its task. We could just load every plugin at startup, switch between them internally when necessary, and never unload them. However, this could become a problem if the number of available plugins increases in the future. Then, loading all plugins could take some time and slow down the entire bootware process. In many cases, some or most of the plugins would never be used and loading them wouldn't be necessary at all. Therefore, it seems far more reasonable to load and unload plugins dynamically when needed.

Security is also a must have feature. Consider the following scenario: The bootware component is used by multiple separate users who can share plugins using a plugin repository. A malicious user could create a new plugin and upload it to the repository. This plugin can contain virtually any code. For example, it could erase all files or open a back door in the system when it is executed. Other users might trust the plugin author and try the plugin without checking its code first. Proper security feature might be able to prevent harm in such situations. Due to time restrictions, plugin security will not be discussed further in this thesis, but it's still vital to select the right framework now, so that security features can be implemented in the future.

We also consider some non-functional features that might influence the selection. There is already a plugin framework in use in the SimTech project, so it could be beneficial to choose the same framework, because the necessary knowledge and experience already exists. The requirements section also mentioned that using software based on open standards is encouraged. If possible, the complexity should be low while still providing all the necessary functional properties. Frameworks with high popularity and an active development community might be more mature or provide more documentation and support.

| | | Plugin Frameworks | | | |
|-----------------------|--------------------|-------------------|-------------------|------------------|-------------------|
| | | SPI ² | JSPF ³ | JPF ⁴ | OSGi ⁵ |
| <i>functional</i> | Dynamic Loading | ✗ | ✗ | ✓ | ✓ |
| | Security | ✗ | ✗ | ✗ | ✓ |
| <i>non-functional</i> | Used in SimTech | ✗ | ✗ | ✗ | ✓ |
| | Standard | (✓) | ✗ | ✗ | ✓ |
| | Complexity | low | low | medium | high |
| | Popularity | medium | low | medium | high |
| | Active Development | ✓ | ✗ | ✗ | ✓ |

Table 8.1: Feature comparison of Java plugin frameworks

Table 8.1 shows a comparison of four Java plugin frameworks, the first of which is the Service Provider Interface (SPI)⁶. It is an extension mechanism integrated in Java which is a little more advanced than the manual extension mechanism described in Section 6.4. It is also based on a set of interfaces and abstract classes that have to be implemented by an extension. In the case of SPI, these interfaces and abstract classes are called services and a specific implementation of such a service is called service provider. However, unlike in the manual approach, specific implementations are loaded from .jar files in specific directories or in the class path. These .jar files also include metadata to identify the different service providers.

SPI is easy to use, doesn't depend on any external libraries, is well documented, and mature, since it is used in the Java Runtime Environment (JRE). One could also say that it is somewhat standardized, since it is part of Java. But as we can see in Table 8.1 on the left, it neither supports dynamic loading, nor security features and is therefore not a good fit for our needs.

²<http://docs.oracle.com/javase/6/docs/api/java/util/ServiceLoader.html>

³<https://code.google.com/p/jspf>

⁴<http://jpf.sourceforge.net>

⁵<http://www.osgi.org>

⁶<http://docs.oracle.com/javase/6/docs/api/java/util/ServiceLoader.html>

The next contender is the Java Simple Plugin Framework (JSPF)³, an open-source plugin framework build for small to medium sized projects. Its focus is simplicity and the author explicitly states that it is not intended to replace JPF or OSGi⁷. As a result it is lightweight and easy to use but does not support advanced features like dynamic loading or security.

Java Plugin Framework (JPF)⁴ is another open-source plugin framework. Compared to JSPF it's a little more complex and popular. As we can see in Table 8.1, it also supports dynamic loading. However, the last version was released in 2007 and development seems to have stopped. This is not necessarily bad but might show that there will be no future development of this framework.

This leaves us with the final contender, which is Open Service Gateway initiative (OSGi)⁵, a plugin framework standard developed by the OSGi Alliance. It provides a general-purpose Java framework that supports the deployment of extensible bundles [24]. The right column of Table 8.1 shows, that it supports dynamic loading, as well as security. OSGi is under active development, fairly popular, and has also been used in the SimTech project. Compared to the other alternatives, it is pretty complex, but considering the other factors, it is the only real alternative. Therefore we will use OSGi to provide the extensibility required for the bootware.

Since OSGi by itself is only a standard, we still have to select an OSGi implementation. As with all other libraries and frameworks we use, we are looking for an open-source implementation, so we will ignore commercial OSGi implementations. There are three open-source OSGi implementations to choose from: Apache Felix⁸, Eclipse Equinox⁹, and Knopflerfish¹⁰. All of them are under active development and implement the OSGi core framework specification, as well as the OSGi security specification (among others). We will be using Apache Felix, since it is already being used in the SimTech project. But it should be straight forward to change to another implementation in the future if necessary, since they all implement the same specification and should therefore be - at least in theory - completely interchangeable.

8.3.2 PubSub Libraries

Many of the well know messaging middlewares offer support for PubSub, for example ActiveMQ¹¹, RabbitMQ¹², and ZeroMQ¹³. But, since we are looking for an internal communication

⁷<https://code.google.com/p/jspf/wiki/FAQ>

⁸<http://felix.apache.org>

⁹<http://eclipse.org/equinox>

¹⁰<http://www.knopflerfish.org>

¹¹<http://activemq.apache.org>

¹²<http://www.rabbitmq.com>

¹³<http://zeromq.org>

mechanism only, all of these solutions are somewhat overpowered. We don't have to worry about network problems, so we don't need guaranteed delivery or message queuing capabilities. We also don't need persistence or transactional capabilities. We don't have to handle millions of subscribers or events, so high scalability isn't a concern. We don't even necessarily need asynchronous communication. Instead, we need a lightweight in-memory solution. Therefore we will ignore the middleware heavyweights and look for smaller PubSub libraries.

We have a few functional requirements that a library has to support for our use case. These can be seen on the left-hand side of Table 8.2. Weak references are an important feature, since we have a lot of plugins that will register as listeners to the event bus. These plugins can be removed at any time and weak references allow us to remove them without explicitly unregistering them from the event bus. Instead of crashing, the event bus will just ignore references to listeners that don't exist anymore. Even if we explicitly unregister all our plugins, weak references give us a safety net if we forget it at some point.

We also need support for an event hierarchy. This allows us to model our events in a very fine grained modular fashion and organize them into logical groups. It also allows listeners to react to a whole group of specific events or only to a small subset of such a group. A filtering feature gives us even more control over what events a listener will react to. It allows us to filter out specific events, for example by their content, to handle them differently, or to ignore them.

We also want event handlers to be invoked synchronously. If an event is published, all event handlers for this event should be executed one after another until they are finished. Only then should the program continue execution. But asynchronous invocation might still be useful in

some cases, so we also add it here.

| | | PubSub Libraries | | | | |
|-----------------------|--------------------------|------------------------|-------------------------------|-------------------------------------|-------------------------|-----------------------------|
| | | EventBus ¹⁴ | Guava Event Bus ¹⁵ | Simple Java Event Bus ¹⁶ | MBassador ¹⁷ | Mycila PubSub ¹⁸ |
| <i>functional</i> | Weak References | ✓ | ✗ | ✓ | ✓ | ✓ |
| | Event Hierarchy | ? | ✓ | ? | ✓ | ✓ |
| | Filtering | ✓ | ✗ | ✓ | ✓ | ✗ |
| | Sync. Invocation | ✓ | ✓ | ✓ | ✓ | ✓ |
| | Async. Invocation | ✓ | ✓ | ✓ | ✓ | ✓ |
| <i>non-functional</i> | Popularity | high | medium | low | medium | low |
| | Maturity | high | medium | medium | medium | medium |
| | Documentation | high | low | low | medium | medium |

Table 8.2: Feature comparison of Java PubSub libraries

The first library we look at is EventBus. As can be seen in Table 8.2 on the left, EventBus supports most of the functionality we need. From the libraries presented here it is also the oldest one, so it is mature, fairly popular and well documented. However, outdated coding practices and many features also make it fairly heavyweight. Guava Event Bus on the other hand is a rather simple PubSub library. It is part of the Google core libraries for Java 1.6+ and is therefore fairly popular, but it lacks in documentation. It also doesn't support weak references and filtering, which doesn't make it a good fit for our use case.

Simple Java Event Bus is a simpler alternative to EventBus. It lacks some of the advanced features of EventBus but is also easier to use. Compared to the other libraries it is not that popular and lacks in documentation. MBassador is a light-weight and performance minded PubSub library. As we can see in Table 8.2, it supports all functional features that we need and some more. It is also relatively mature, has good enough documentation and is somewhat popular. Finally, we have Mycila PubSub, a modern replacement for EventBus. It supports all

¹⁴<http://eventbus.org/>

¹⁵<https://code.google.com/p/guava-libraries/wiki/EventBusExplained>

¹⁶<https://code.google.com/p/simpleeventbus/>

¹⁷<https://github.com/bennidi/mbassador>

¹⁸<https://github.com/mycila/pubsub>

the functional features we need, except filtering. Its documentation is good enough, but since it is relatively new, it's not very popular yet and may lack in maturity.

From the alternatives presented here, MBassador seems to be the only one that offers all the functionality we need combined with relative maturity and good documentation. We will therefore use it for our implementation.

8.3.3 State Machine Libraries

Since we want to implement the bootware process as a finite state machine, we must now decide how we will do it. It would certainly be possible to go with a hand made state machine implementation, but the time for this thesis is limited and we should use it for the actual design of the bootware. Therefore, it would be better to use an existing state machine library. In general, we are looking for an event-driven FSM, which allows us to define a set of states and transition between those states when specific events occur. Ideally we would prefer a standardized way to define the FSM and avoid proprietary formats. But we also don't want the FSM to be overly complex to use. We also want to avoid introducing additional conversion

or compilation steps. Table 8.3 shows six state machine libraries available for Java.

| | State Machine Libraries | | | | | |
|----------------------|-----------------------------|------------------------|-------------------|---------------------------|-----------------------------------|----------------------|
| | Commons SCXML ¹⁹ | EasyFlow ²⁰ | SMC ²¹ | stateless4j ²² | squirrel-foundation ²³ | Unimod ²⁴ |
| Event Driven | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Description Language | SCXML | Java | .sm | Java | Java, SCXML | UML, XML |
| Complexity | med. | low | med. | low | low | high |
| Popularity | med. | low | med. | low | med. | med. |
| Maturity | low | med. | high | med. | med. | high |
| Documentation | med. | low | high | low | high | high |

Table 8.3: Feature comparison of Java state machine libraries.

Apache Commons SCXML¹⁹ aims to be a java state machine engine that is capable of executing state machines defined as State Chart XML (SCXML). SCXML is a working draft specification for a general-purpose event-based state machine language that is currently being developed by the World Wide Web Consortium (W3C)[31]. Apache Commons SCXML looks like a good match for our needs, since it is event-based and also using a (soon to be) standard. But the current state of the implementation seems to be lacking since the SCXML specification has changed a lot. The most recent release is version 0.9, which was released in late 2008. It is about to be replaced by version 2.0 that is currently being worked on and includes major changes, but a release date is not yet in sight²⁵.

EasyFlow²⁰ is a simple and lightweight FSM for Java. It is event-driven, but only supports describing the FSM directly in Java code. Compared to the other alternatives, it is not very well documented and not very popular. There also is State Machine Compiler (SMC)²¹, a state machine compiler that targets fifteen different programming languages, including Java. It

¹⁹<http://commons.apache.org/proper/commons-scxml/>

²⁰<https://github.com/Beh0lder/EasyFlow>

²¹<http://smc.sourceforge.net/>

²²<https://github.com/oxo42/stateless4j>

²³<https://github.com/hekailiang/squirrel>

²⁴<http://unimod.sourceforge.net/>

²⁵<http://commons.apache.org/proper/commons-scxml/roadmap.html>

generates FSMs from a definition in *.sm* files. SMC is mature and has good documentation, but the use of an extra definition language and the extra step of compiling it into a Java representation seem to be too complicated for our needs.

Stateless4j²² is a lightweight library for creating FSMs directly in Java code. Compared to the other alternatives, it lacks in documentation and doesn't seem to be very popular. Squirrel-foundation²³ is a lightweight, flexible, and extensible FSM library for Java. Although relatively new, it is feature rich, well documented and relatively popular. It also supports some advanced features that might be useful. For example, it supports SCXML import and export. Finally, there is Unimod²⁴, a project that can create FSMs from UML descriptions created by an eclipse plugin. Unlike the other alternative, Unimod aims to create a unified methodology for application development and not just a library. This seems to be too complex for our needs.

From the alternatives presented here, Apache Commons SCXML would be our first choice if the standard and the implementation were more mature. At this point in time however, this is not the case. For this diploma thesis we will use squirrel-foundation to implement the state machine. If Apache Commons SCXML becomes a viable option in the future, replacing squirrel-foundation could be considered. Since it supports exporting the state machine as SCXML, this could be used to ease a possible transition.

8.4 Context

Listing 8.1 shows an exemplary context in XML form. As we can see in line 2-4, it is required to define the infrastructure, connection, and payload plugins that should be used during the bootstrapping process by supplying the name of the plugin *.jar*. It is also possible to specify a call provisioning engine plugin, as can be seen in line 6. This is optional and will only be used on the first request, when the remote bootware will also call a provisioning engine to provision the workflow middleware. This is also where the service package reference in line 8 will be used, which points to the service package that should be provisioned by the provisioning engine called by the call payload plugin. In line 10-26 we can also see the optional configuration list. If it is supplied in the context, it will override configuration values with the same name in the default configuration list that can be set with the *setConfiguration* operation. If it is not supplied, the default configuration will be used.

context.xml

```

1 <context>
2   <infrastructurePlugin>aws-ec2.jar</infrastructurePlugin>
3   <connectionPlugin>ssh.jar</connectionPlugin>
4   <payloadPlugin>opentosca.jar</payloadPlugin>
5   <!--Optional:-->
6   <callPayloadPlugin>callopentosca.jar</callPayloadPlugin>
7   <!--Optional:-->
8   <servicePackageReference>opentosca.csar</servicePackageReference>
9   <!--Optional:-->
10  <configurationList>
11    <entry>
12      <key>aws</key>
13      <value>
14        <configuration>
15          <entry>
16            <key>secretKey</key>
17            <value>874w5zhpwe98tzhg0w87ser049tadsiph</value>
18          </entry>
19          <entry>
20            <key>accessKey</key>
21            <value>g9w276og9746gw5</value>
22          </entry>
23        </configuration>
24      </value>
25    </entry>
26  </configurationList>
27</context>
```

Listing 8.1: Sample context represented in XML.

8.5 Web Service Interface

In Section 6.3 we decided to use web service calls and returns as external communication mechanism and in Section 6.7 we decided to pass along a context. Now, we need to define the interface that will be made available by the web service to the outside. We obviously need the two main operations, deploy and undeploy, to be available from the outside. In Section 6.7 we also described the *setConfiguration* operation that has to be supported.

8.5.1 Deploy

The *deploy* operation will be called by at least two different components. Once by the bootware modeler plugin to deploy the remote bootware and the workflow middleware, and then each time the provisioning manager needs to provision a new service during a workflow execution. Listing 8.2 shows an exemplary deploy request as soap message. In line 6 we can see that the *deploy* method is called with the context provided as argument in line 7-11. In this particular example, only the required plugins are specified, which could be a call from the provisioning manager.

deploy-request.xml

```

1 <soapenv:Envelope
2   xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
3   xmlns:rem="http://remote.bootware.simtech.org/">
4   <soapenv:Header/>
5   <soapenv:Body>
6     <rem:deploy>
7       <context>
8         <infrastructurePlugin>aws-ec2.jar</infrastructurePlugin>
9         <connectionPlugin>ssh.jar</connectionPlugin>
10        <payloadPlugin>opentosca.jar</payloadPlugin>
11      </context>
12    </rem:deploy>
13  </soapenv:Body>
14 </soapenv:Envelope>
```

Listing 8.2: Sample deploy request in a soap message.

The response that is return once the request has been executed successfully is shown in Listing 8.3. It contains a list of endpoint references in line 5-10, which contains a reference to the payload that was deployed during the request, in this case OpenTOSCA.

If the deploy request somehow failed, a soap message containing a soap fault will be returned, which is shown in Listing 8.4. It contains a fault string with an error description in line 5, as well as the original DeployException that was thrown by the deploy operation in line 7-10.

```
_____ deploy-response.xml _____
1 <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
2   <S:Body>
3     <ns2:deployResponse xmlns:ns2="http://remote.bootware.simtech.org/">
4       <return>
5         <endpoints>
6           <entry>
7             <key>opentosca</key>
8             <value>http://aws.com:8080/</value>
9           </entry>
10          </endpoints>
11        </return>
12      </ns2:deployResponse>
13    </S:Body>
14  </S:Envelope>
```

Listing 8.3: Sample deploy response in a soap message.

```
_____ deploy-error.xml _____
1 <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
2   <S:Body>
3     <S:Fault xmlns:ns4="http://www.w3.org/2003/05/soap-envelope">
4       <faultcode>S:Server</faultcode>
5       <faultstring>infrastructureType cannot be empty</faultstring>
6       <detail>
7         <ns2:DeployException
8           xmlns:ns2="http://remote.bootware.simtech.org/">
9           <message>infrastructureType cannot be empty</message>
10          </ns2:DeployException>
11        </detail>
12      </S:Fault>
13    </S:Body>
14  </S:Envelope>
```

Listing 8.4: Sample deploy error in a soap message.

8.5.2 Undeploy

Like the *deploy* operation, the *undeploy* operation will be called by multiple components to reverse the actions that where previously made by deploy operations. Listing 8.5 shows an exemplary undeploy request in a soap message. As argument it contains one or more endpoint references to already deployed payloads, as can be seen in line 7-12.

```
----- undeploy-request.xml -----
```

```

1 <soapenv:Envelope
2   xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
3   xmlns:rem="http://remote.bootware.simtech.org/">
4   <soapenv:Header/>
5   <soapenv:Body>
6     <rem:undeploy>
7       <endpoints>
8         <entry>
9           <key>opentosca</key>
10          <value>http://aws.com:8080/</value>
11        </entry>
12      </endpoints>
13    </rem:undeploy>
14  </soapenv:Body>
15 </soapenv:Envelope>
```

Listing 8.5: Sample undeploy request in a soap message.

When all payloads have been undeployed successfully, a response will be send, as shown in Listing 8.6. The response is empty since there is nothing interesting to return.

```
----- undeploy-response.xml -----
```

```

1 <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
2   <S:Body>
3     <ns2:undeployResponse
4       xmlns:ns2="http://remote.bootware.simtech.org/">
5     </S:Body>
6   </S:Envelope>
```

Listing 8.6: Sample undeploy response in a soap message.

In case of a failure, an error will be return. As can be seen in Listing 8.7, it has the same layout

as the error returned by the deploy operation. It contains a soap fault string in line 5 and the original UndeployException thrown by the undeploy operation in line 7-10.

```

1   _____ undeploy-error.xml _____
2   <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
3     <S:Body>
4       <S:Fault xmlns:ns4="http://www.w3.org/2003/05/soap-envelope">
5         <faultcode>S:Server</faultcode>
6         <faultstring>Undeploy operation failed</faultstring>
7         <detail>
8           <ns2:UndeployException
9             xmlns:ns2="http://remote.bootware.simtech.org/">
10            <message>Undeploy operation failed</message>
11          </ns2:UndeployException>
12        </detail>
13      </S:Fault>
14    </S:Body>
</S:Envelope>

```

Listing 8.7: Sample undeploy error in a soap message.

8.5.3 Set Configuration

In addition to the main deploy and undeploy operations, the bootware web service also supports the *setConfiguration* operation. Using this operation, the configuration can be set independently from deploy requests if necessary. Listing 8.8 shows an exemplary setConfiguration request. In line 7-23, it contains a configuration list, which can contain one or more configuration sets. Each configuration set is made up of one or more configuration entries, which are key value pairs, where the key describes the configuration type and the value the actual configuration value. What content a particular key has to contain depends on what the plugins are looking for when they read the configuration. In the example code in line 9, we send one configuration set for AWS, which consists of two credentials, a secret key in line 12-15 and an accessKey in line 16-19.

If the setConfiguration operation was successful, the response in Listing 8.9 will be returned. Again, it is empty, since there is nothing interesting to return.

setConfiguration-request.xml

```

1 <soapenv:Envelope
2   xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
3   xmlns:rem="http://remote.bootware.simtech.org/">
4   <soapenv:Header/>
5   <soapenv:Body>
6     <rem:setConfiguration>
7       <configurationList>
8         <entry>
9           <key>aws</key>
10          <value>
11            <configuration>
12              <entry>
13                <key>secretKey</key>
14                <value>874w5zhpse98tzhg0w87ser049tadsiph</value>
15              </entry>
16              <entry>
17                <key>accessKey</key>
18                <value>g9w276og9746gw5</value>
19              </entry>
20            </configuration>
21          </value>
22        </entry>
23      </configurationList>
24    </rem:setConfiguration>
25  </soapenv:Body>
26</soapenv:Envelope>

```

Listing 8.8: Sample setConfiguration request in a soap message.

setConfiguration-response.xml

```

1 <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
2   <S:Body>
3     <ns2:setConfigurationResponse
4       xmlns:ns2="http://remote.bootware.simtech.org/">
5   </S:Body>
6 </S:Envelope>

```

Listing 8.9: Sample setConfiguration response in a soap message.

Like the deploy and undeploy operations, the setConfiguration operation also returns an error message if the operation failed. As can be seen in Listing 8.10, it also contains a soap fault string in line 5 and the original SetConfigurationException thrown by the setConfiguration operation in line 7-10.

```

----- setConfiguration-error.xml -----
1 <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
2   <S:Body>
3     <S:Fault xmlns:ns4="http://www.w3.org/2003/05/soap-envelope">
4       <faultcode>S:Server</faultcode>
5       <faultstring>Configuration could not be set</faultstring>
6       <detail>
7         <ns2:SetConfigurationException
8           xmlns:ns2="http://remote.bootware.simtech.org/">
9           <message>Configuration could not be set</message>
10          </ns2:SetConfigurationException>
11        </detail>
12      </S:Fault>
13    </S:Body>
14  </S:Envelope>
-----
```

Listing 8.10: Sample setConfiguration error in a soap message.

8.5.4 Get Active Payloads

The getActivePayloads operation is called by the provisioning manager to retrieve already deployed provisioning engines. If a provisioning engine it needs is already active, it doesn't have to call the bootware to provision a new one. As already explained in Section 6.8 this is only needed in the remote bootware and therefor we only implement it there. Listing 8.11 shows a getActivePayloads request in a SOAP message. No parameters are required.

The response that is returned contains a list of all payloads that where active when the request was made. As we can see in Listing 8.12 lines 6-11, it contains a payloads list with zero or more entries. Each entry consists of a key/value pair, where the key identifies the payload and the value contains a URL to the payload. In this example, the entry points to an OpenTOSCA container instance.

```
getActivePayloads-request.xml
1 <soapenv:Envelope
2   xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
3   xmlns:rem="http://remote.bootware.simtech.org/">
4     <soapenv:Header/>
5     <soapenv:Body>
6       <rem:getActivePayloads/>
7     </soapenv:Body>
8   </soapenv:Envelope>
```

Listing 8.11: Sample getActivePayloads request in a soap message.

```
getActivePayloads-response.xml
1 <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
2   <S:Body>
3     <ns2:getActivePayloadsResponse
4       xmlns:ns2="http://remote.bootware.simtech.org/">
5       <return>
6         <payloads>
7           <entry>
8             <key>opentosca</key>
9             <value>http://aws.com:8080/</value>
10            </entry>
11          </payloads>
12        </return>
13      </ns2:getActivePayloadsResponse>
14    </S:Body>
15  </S:Envelope>
```

Listing 8.12: Sample getActivePayloads response in a soap message.

If the getActivePayloads request failed for some reason, an error message is returned. As can be seen in Listing 8.13, it contains a soap fault string in line 5 and the original GetActivePayloadsException thrown by the getActivePayloads operation in line 7-10.

```

----- getActivePayloads-error.xml -----
1 <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
2   <S:Body>
3     <S:Fault xmlns:ns4="http://www.w3.org/2003/05/soap-envelope">
4       <faultcode>S:Server</faultcode>
5       <faultstring>Error retrieving active payloads</faultstring>
6       <detail>
7         <ns2:GetActivePayloadsException
8           xmlns:ns2="http://remote.bootware.simtech.org/">
9           <message>Error retrieving active payloads</message>
10          </ns2:GetActivePayloadsException>
11        </detail>
12      </S:Fault>
13    </S:Body>
14  </S:Envelope>
-----
```

Listing 8.13: Sample getActivePayloads error in a soap message.

8.5.5 Shutdown

The shutdown operation triggers the shutdown procedure. During this procedure, all active payloads will be undeployed. The local bootware will also forward this request to the remote bootware and wait for a response so that it can deprovision the remote bootware before shutting down itself. Listing 8.14 shows a shutdown request in a SOAP message. No parameters are required.

```

----- shutdown-request.xml -----
1 <soapenv:Envelope
2   xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
3   xmlns:rem="http://remote.bootware.simtech.org/">
4   <soapenv:Header/>
5   <soapenv:Body>
6     <rem:shutdown/>
7   </soapenv:Body>
8 </soapenv:Envelope>
-----
```

Listing 8.14: Sample shutdown request in a soap message.

If the additional processes executed during shutdown (i.e. undeploy payloads or middleware)

were successful, the response in Listing 8.15 will be returned.

```
1   shutdown-response.xml _____
2   <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
3     <S:Body>
4       <ns2:shutdownResponse
5         xmlns:ns2="http://remote.bootware.simtech.org/">
6     </S:Body>
7   </S:Envelope>
```

Listing 8.15: Sample shutdown response in a soap message.

If the additional processes failed for some reason, an error response like the one showed in Listing 8.16 will be returned. It contains a soap fault string in line 5 and the original ShutdownException thrown by the shutdown operation in line 7-10.

```
1   shutdown-error.xml _____
2   <S:Envelope xmlns:S="http://schemas.xmlsoap.org/soap/envelope/">
3     <S:Body>
4       <S:Fault xmlns:ns4="http://www.w3.org/2003/05/soap-envelope">
5         <faultcode>S:Server</faultcode>
6         <faultstring>Shutdown operation failed</faultstring>
7         <detail>
8           <ns2:ShutdownException
9             xmlns:ns2="http://remote.bootware.simtech.org/">
10            <message>Shutdown operation failed</message>
11          </ns2:ShutdownException>
12        </detail>
13      </S:Fault>
14    </S:Body>
15  </S:Envelope>
```

Listing 8.16: Sample shutdown error in a soap message.

8.6 Plugins

Now, we will describe the implementation of a few plugins. We implemented an infrastructure plugin that can create and remove EC2 instances in Amazon's cloud. We created a connection plugin that allows the bootware to connect to a remote system via SSH and then execute commands on, or upload files to this system.

8.6.1 AWS EC2 Plugin

This infrastructure plugin allows the bootware to create and remove EC2 instances in Amazon's cloud. It uses the AWS SDK for Java²⁶ to implement this functionality. This SDK specifies a specific set of action that have to be taken to start an EC2 instance, which we map onto the operations defined by each infrastructure plugin, i.e. initialize, shutdown, deploy, and undeploy, as described in Section 6.5. Figure 8.3 shows a simplified overview of these actions and how they map onto the infrastructure plugin operations.

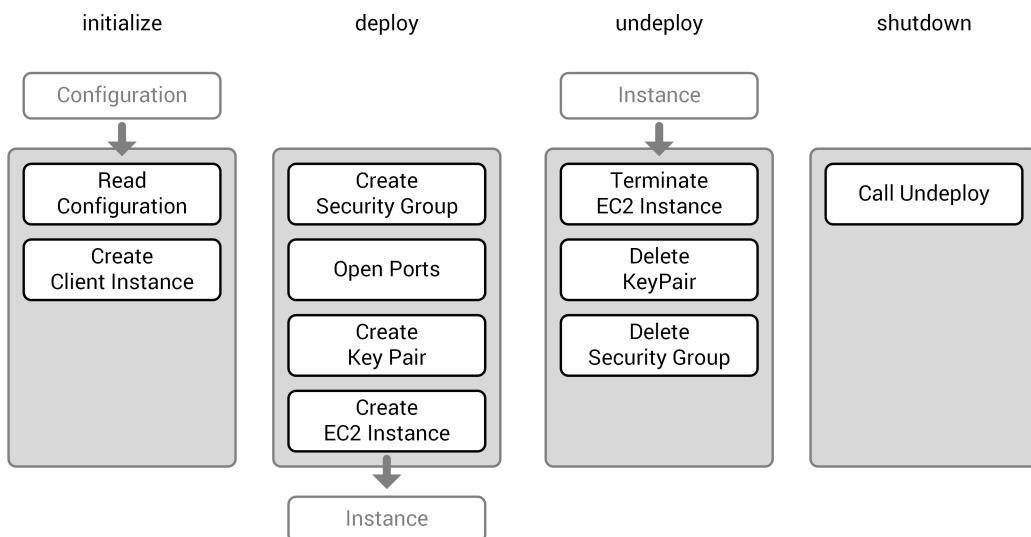


Figure 8.3: The operations implemented by the AWS EC2 plugin.

The initialize operation, shown on the left of Figure 8.3, which is called once when the plugin is loaded, creates a client instance, which is an object on which all the following actions

²⁶<http://aws.amazon.com/sdkforjava/>

will be called. The client instance is bound to a specific AWS region, which is read from the configuration object that is passed into the initialize operation.

As we can see in the deploy operation in Figure 8.3, we first have to create a security group²⁷. Security groups are essentially virtual firewalls that allow or deny traffic to and from all EC2 instances associated with it. EC2 instances have to be associated with a security group, so we have to create one. In the next step we open all ports in this security group that we later want to use for communication. Which ports we open is determined by reading the configuration object. We also have to create a SSH key pair and retrieve the private key, which we later use when we connect to this EC2 instance via SSH. In the last step we create the actual EC2 instance. Once it is up and running, the deploy operation is finished and returns an instance object which contains the URL where the EC2 instance can be reached, as well as the private key for SSH access.

The undeploy operation reverses the deploy operation. First, it terminates the EC2 instance. Once the instance is stopped, the key pair and the security group that were created earlier are removed. We don't have to close the ports we opened, since they are part of the security group and don't exist anymore once the security group is removed. After this, the EC2 instance created earlier is successfully removed. There are no further actions necessary during the shutdown operation, but for safety we call the undeploy operation, in case it wasn't called earlier.

8.6.2 SSH Plugin

This connection plugin allows the bootware to connect to a remote system via SSH. It uses the Ganymed SSH-2 library²⁸, which implements the SSH-2 protocol in Java. Figure 8.4 shows a simplified overview of the actions necessary to create a SSH connection and how they map onto the connection plugin operations.

No actions are taken in the initialize operation. During the connect operation, we first have to create a connection object, which is bound to a certain host name, i.e. the IP address of the remote system that we want to connect to. We get this address from the instance object passed into the connect operation. Then we have to authenticate this connection. Multiple authentication methods are supported by SSH-2 protocol, including password and public key authentication. The necessary values for these authentication methods are read from the instance object passed into the connect operation. Once the connection is authenticated, a

²⁷<http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/using-network-security.html>

²⁸<https://code.google.com/p/ganymed-ssh-2/>

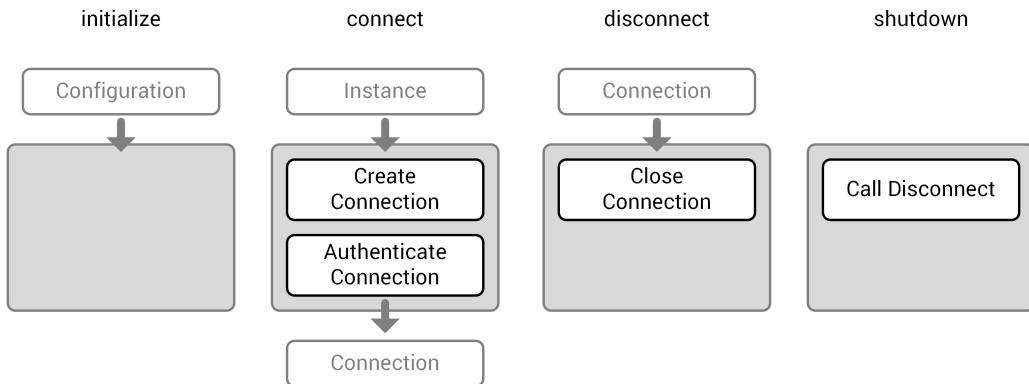


Figure 8.4: The operations implemented by the SSH plugin.

connection object is returned, which supports the execute and upload operation that other components can use.

The disconnect operation simply closes the connection associated with the connection object that is passed into it. The disconnect operation is also called by the shutdown operation at the end of the plugin life cycle to close any connection that might still be open.

8.6.3 Remote Bootware Plugin

This payload plugin allows the local bootware to install the remote bootware on a remote system. Figure 8.5 shows a simplified overview of the steps involved in the installation of the remote bootware and how they map onto the payload plugin operations. The undeploy and stop operations were omitted since they are not really required in this case.

In this plugin, the initialize operation does not take any actions. The deploy operation first uses the operations provided by the connection object it receives as input to upload the remote bootware files from the local to the remote machine. Then, it checks if the Java version required to execute the remote bootware is present. If not, it installs the required Java version. The remote bootware should now be ready to start. In the start operation a command to execute the remote bootware is sent to the remote machine. Then, the port for the remote bootware web interface is polled until a response is received, which means that the remote bootware should now be ready. Finally, the URL to the remote bootware is returned.

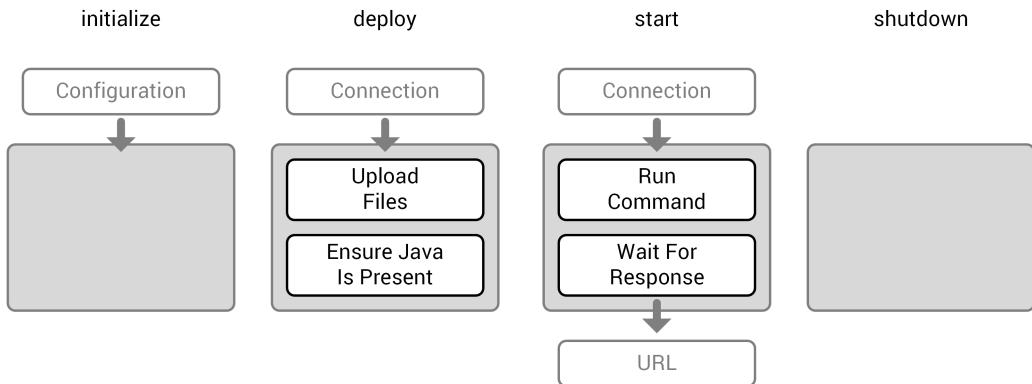


Figure 8.5: The operations implemented by the remote bootware plugin.

8.6.4 OpenTOSCA Plugin

This payload plugin allows the bootware to install an OpenTOSCA container on an EC2 instance. It executes the installation steps described in the OpenTOSCA manual over a connection provided by a connection plugin. Figure 8.6 shows a simplified overview of the steps involved in the installation of OpenTOSCA and how they map onto the payload plugin operations. The undeploy and stop operations where omitted since they are not really required in this case.

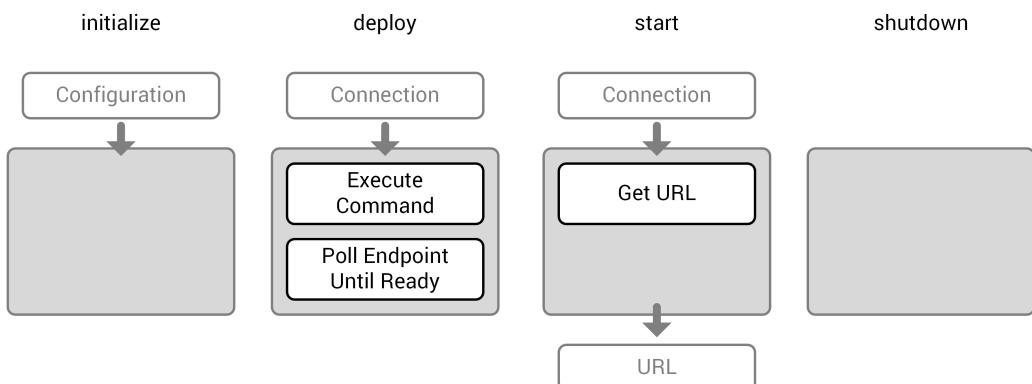


Figure 8.6: The operations implemented by the OpenTOSCA plugin.

The setup procedure for OpenTOSCA is very simple. Only one command has to be executed over ssh, which will automatically download and install all necessary components. After that, port 8080 on the EC2 instance is polled periodically until a connection is possible, which means that the installation process is finished. The start operation only has to return the

URL pointing to the OpenTOSCA instance, since OpenTOSCA was already started by the installation script.

8.6.5 File Logger Plugin

This event plugin logs all events generated by the bootware to a text file. Unlike the other plugins, it does not implement any other interface operations apart from the standard initialize and shutdown operations. Rather, it uses event handlers to react to specific events. Figure 8.7 shows a simplified overview of the implementation of this plugin.

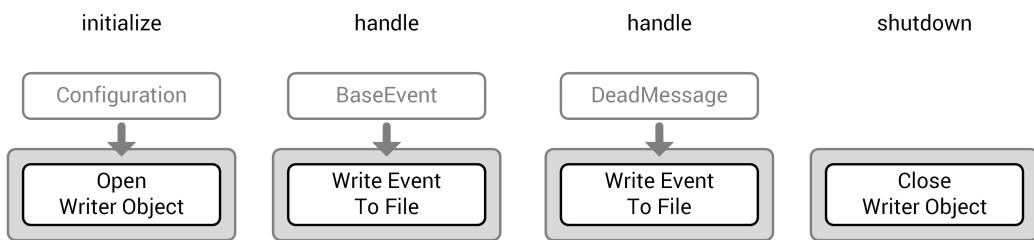


Figure 8.7: The operations implemented by the file logger plugin.

The initialize operation creates a writer object which opens a text file to write into. This writer object is then used by the two event handlers shown in the middle to write the events they receive into this file. The event handler shown on the left reacts to all events of the type BaseEvent, which is the parent event of all events generated by the bootware. Therefore, it logs any event generated by the bootware into the text file. The event handler shown on the right reacts to a special DeadMessage event type generated by the PubSub library we use, MBassador. This event is generated each time an event is published to the event bus to which no one subscribed. Those events are not received by any listener and are therefore dead. We log them here for debugging purposes. The shutdown operation just closes the write object that was created by the initialize operation.

9 Future Work

With this diploma thesis we created a foundation which, while functional right now, might still need more work to become fully functional and useful in real working environment. In this chapter we present some opportunities for future improvements.

9.1 More Plugins and a Plugin Repository

For this diploma thesis we only implemented a few plugins. The plugin selection will certainly have to be extended in the future to cover a wider range of cloud providers (or other infrastructure types), connection mechanisms, and payloads. Along with a greater variety of plugins, a plugin repository, as described in Subsection 6.4.2 would be beneficial. It would further decrease code duplication and facilitate plugin sharing. For this, a fitting repository format would have to be found and various other questions, such as security, need to be answered. On the implementation side, the integration of a plugin repository should be fairly straight forward. A mechanism to synchronize the local plugin directory with the repository has to be implemented and executed before the plugins are loaded. The code for loading plugins that is in place now doesn't necessarily need to be changed for this.

9.2 Secure Communication and Secure Plugins

As we already mentioned in Section 6.3, it is necessary to secure the communication with the bootware, since it contains sensitive login information that should not be publicly accessible. For this, the communication has to be encrypted, which can be done by using the WS-Security¹ SOAP extension for the web service communication. In Subsection 8.3.1 we also mentioned that security for plugins could be a problem. OSGi provides an optional security layer based on Java permissions² that can be used to apply permission based security. For example,

¹https://www.oasis-open.org/committees/tc_home.php?wg_abbrev=wss

²<http://docs.oracle.com/javase/7/docs/api/java/security/Permission.html>

it should be possible to only allow plugins to access specific files or folders with Java file permissions³. As part of this work, it could also make sense to investigate other possible security enhancements to the bootware.

9.3 Better SimTech Modeler Integration

The integration of the bootware with the SimTech Modeler using the bootware plugin can also be extended in the future. The current integration is fairly minimal and only supports the most basic functionality. Improvements could be made to give the user more feedback on the provisioning progress. Additionally, a more intuitive way to configure the bootware could be implemented, for example with a graphical configuration interface that allows for the selection of plugins and configuration values.

9.4 Better Failure Management

Currently, the bootware will fail in many cases where it could continue, if the user could influence error recovery. For example, if for some reason a connection can't be established with a cloud provider, the bootware will abort and undeploy already provisioned payloads. This could happen in the middle of a workflow execution, where multiple services are deployed in different clouds. In this scenario, the ability for the user to select an alternative cloud provider for this one service could enable the bootware to continue instead of aborting, which would in turn allow the workflow execution to finish, instead of failing. Failure management mechanisms such as this would improve the usability of the bootware.

9.5 Crash Recovery

In Section 6.9 we mentioned that we store active instances in-memory. Right now, if the bootware crashes during the bootstrapping process with instances still active, there is no way to continue the process after a restart or at least undeploy remaining instances. These remaining instances will have to be removed by hand, which is not ideal. This could be improved by storing active instances in some sort of persistent storage, so that they can still be retrieved after a crash for recovery purposes.

³<http://docs.oracle.com/javase/7/docs/api/java/io/FilePermission.html>

10 Summary and Conclusion

In this diploma thesis we presented a design for a bootware system that is able to deploy various provisioning engines as well as a workflow middleware into remote environments, on-demand and fully automatic. Starting from previous work, we compared possible architecture alternatives and selected a 2-tiered architecture consisting of generic local and remote bootware components. We also introduced the notion of a bootware adapter to connect the local bootware component to a specific modeler. We described a web service interface to allow various components to communicate with the bootware. We made this architecture extensible via plugins and described five different plugin types. We also added an event bus to allow plugin to create and react to events. We described the execution flow that was implemented with a finite state machine.

Then, we presented details of the implementation of the bootware components and the integration into the SimTech scientific workflow management system. We described a specific implementation of the bootware adapter, the bootware plugin, an eclipse plugin that integrates the bootware into the existing SimTech Modeler environment. We explained the bootware core library that is used as foundation for both the local and remote bootware implementation. We also selected Apache Felix to implement the plugins, MBassador for the internal event bus, and squirrel-foundation for the state machine implementation. We described the content of the context object and the various web service requests and responses. Finally, we gave an overview over various plugins, including an infrastructure plugin for Amazon EC2 instances, a SSH connection plugin, a payload plugin for the remote bootware, and an event plugin for file logging.

There were some aspects that we did not further elaborate on. A plugin repository has to be created for the bootware to reach its full potential. Communication with the bootware has to be made secure before it can be used in a real life environment. Other improvements like better modeler integration and failure management should be considered. These tasks are left for future work to explore. In conclusion, there is still work to be done, but the work we presented here should have build a foundation for a part of a system that allows the SimTech SWfMS and other simulation workflow management systems to be used in a fashion that is more in line with scientific work principles.

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Bibliography

- [1] *Asynchronous Method Invocation for CORBA Component Model, Version 1.0*. Tech. rep. Object Management Group, Inc., Apr. 2013. URL: <http://www.omg.org/spec/AMI4CCM/1.0/PDF/>.
- [2] Tobias Binz et al. "OpenTOSCA – A Runtime for TOSCA-based Cloud Applications". In: International Conference on Service-Oriented Computing. LNCS. Springer, 2013. URL: http://www.iaas.uni-stuttgart.de/RUS-data/INPROC-2013-45%20-%20OpenTOSCA_A_Runtime_for_TOSCA-based_Cloud_Applications.pdf.
- [3] Paul E. Black. *Dictionary of Algorithms and Data Structures: alphabet*. NIST. Dec. 2004. URL: <http://xlinux.nist.gov/dads//HTML/alphabet.html>.
- [4] Paul E. Black. *Dictionary of Algorithms and Data Structures: deterministic finite state machine*. NIST. Dec. 2005. URL: <http://xlinux.nist.gov/dads//HTML/determFiniteStateMach.html>.
- [5] Paul E. Black. *Dictionary of Algorithms and Data Structures: finite state machine*. NIST. Aug. 2013. URL: <http://xlinux.nist.gov/dads//HTML/finiteStateMachine.html>.
- [6] Paul E. Black. *Dictionary of Algorithms and Data Structures: state*. NIST. Dec. 2004. URL: <http://xlinux.nist.gov/dads//HTML/state.html>.
- [7] Paul E. Black. *Dictionary of Algorithms and Data Structures: transition function*. NIST. Dec. 2004. URL: <http://xlinux.nist.gov/dads//HTML/transitionfn.html>.
- [8] Werner Buchholz. "The System Design of the IBM Type 701 Computer". In: Institute of Radio Engineers (IRE). Vol. 41. 10. 1953, pp. 1262–1275. URL: <http://ftp.cs.duke.edu/~xwy/publications/cloudcmp-imc10.pdf>.
- [9] *Common Object Request Broker Architecture (CORBA) Specification, Version 3.3 - Part 2: CORBA Interoperability*. Tech. rep. Object Management Group, Inc., Nov. 2012. URL: <http://www.omg.org/spec/CORBA/3.3/Interoperability/PDF/>.
- [10] Edward Curry. "Message-Oriented Middleware". In: *Middleware for Communications*. Wiley, 2004, pp. 1–28. URL: http://www.edwardcurry.org/publications/curry_MfC_MOM_04.pdf.
- [11] *Cyber-Infrastructures and beyond (PN 6)*. SRC Simulation Technology. URL: <http://www.simtech.uni-stuttgart.de/forschung/pn/PN6/index.en.html>.

Bibliography

- [12] *Definition of Provisioning*. ATIS Telecom Glossary. URL: <http://www.atis.org/glossary/definition.aspx?id=2474>.
- [13] Patrick Th. Eugster et al. "The many faces of publish/subscribe". In: *ACM Computing Surveys (CSUR)* 35.2 (June 2003), pp. 114–131. URL: <core.kmi.open.ac.uk/download/pdf/12642066.pdf>.
- [14] *Excellence Initiative at a Glance*. Tech. rep. German Research Foundation, Nov. 2013. URL: http://www.dfg.de/download/pdf/dfg_im_profil/geschaefsstelle/publikationen/exin_broschuere_en.pdf.
- [15] Christoph Fehling and Frank Leymann. *Cloud Computing*. Version 5. Gabler Wirtschaftslexikon. URL: <http://wirtschaftslexikon.gabler.de/Archiv/1020864/cloud-computing-v5.html>.
- [16] *Flexibility of Simulation Workflows*. SRC Simulation Technology. URL: http://www.iaas.uni-stuttgart.de/forschung/projects/simtech/project_flexibility.php.
- [17] David Hollingsworth. *The Workflow Reference Model*. Tech. rep. Workflow Management Coalition, Jan. 1995. URL: <http://www.wfmc.org/standards/docs/tc003v11.pdf>.
- [18] *Human Users in Simulation Workflows*. SRC Simulation Technology. URL: http://www.iaas.uni-stuttgart.de/forschung/projects/simtech/project_humanusers.php.
- [19] James Joyce. *Ulysses*. Project Gutenberg. URL: <http://www.gutenberg.org/files/4300/4300-h/4300-h.htm>.
- [20] Johannes Kirschnick et al. "Toward an Architecture for the Automated Provisioning of Cloud Services". In: *Communications Magazine, IEEE* 48.12 (Dec. 2010), pp. 124–131. URL: <http://jmalcaraz.com/wp-content/uploads/papers/AlcarazCalero-2010-CommMag-Preprint.pdf>.
- [21] Ang Li et al. "CloudCmp: Comparing Public Cloud Providers". In: 10th ACM SIGCOMM conference on Internet measurement. 2010, pp. 1–14. URL: <http://ftp.cs.duke.edu/~xwy/publications/cloudcmp-imc10.pdf>.
- [22] Peter Mell and Timothy Grance. *The NIST Definition of Cloud Computing*. Tech. rep. National Institute of Standards and Technology, Sept. 2011. URL: <http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf>.
- [23] *Modelling of Simulation Workflows*. SRC Simulation Technology. URL: http://www.iaas.uni-stuttgart.de/forschung/projects/simtech/project_modeling.php.
- [24] *OSGi Service Platform core Specification*. Tech. rep. OSGi Alliance, Apr. 2011. URL: <http://www.osgi.org/download/r4v43/osgi.core-4.3.0.pdf>.
- [25] Bhaskar Prasad Rimal, Eunmi Choi, and Ian Lumb. "A Taxonomy, Survey, and Issues of Cloud Computing Ecosystems". In: *Cloud Computing: Principles, Systems and Applications*. Springer, 2010, pp. 21–46.

Bibliography

- [26] Javier Rojas. *The art of the bootstrap*. URL: <http://venturebeat.com/2008/11/20/the-art-of-the-bootstrap/>.
- [27] *Runtime for Simulation Workflows*. SRC Simulation Technology. URL: http://www.iaas.uni-stuttgart.de/forschung/projects/simtech/project_execution.php.
- [28] Valeri Schneider. "Dynamische Provisionierung von Web Services für Simulationsworkflows". Diploma. University Stuttgart, 2013. URL: ftp://ftp.informatik.uni-stuttgart.de/pub/library/medoc.ustuttgart_fi/DIP-3473/DIP-3473.pdf.
- [29] *Service Oriented Architecture : What Is SOA?* The Open Group. URL: <http://www.opengroup.org/soa/source-book/soa/soa.htm>.
- [30] *SLA (Service-level Agreement)*. Gartner, Inc. URL: <http://www.gartner.com/it-glossary/sla-service-level-agreement/>.
- [31] *State Chart XML (SCXML): State Machine Notation for Control Abstraction*. Tech. rep. W3C, May 2014. URL: <http://www.w3.org/TR/2014/WD-scxml-20140529/>.
- [32] *Topology and Orchestration Specification for Cloud Applications Version 1.0*. Tech. rep. OASIS, 2013. URL: <http://docs.oasis-open.org/tosca/v1.0/TOSCA-v1.0.pdf>.
- [33] Luis M. Vaquero et al. "A Break in the Clouds: Towards a Cloud Definition". In: *ACM SIGCOMM Computer Communication Review* 39.1 (Jan. 2009), pp. 50–55. URL: <http://www.sigcomm.org/sites/default/files/CCR/papers/2009/January/1496091-1496100.pdf>.
- [34] Gottfried Vossen and Mathias Weske. "The WASA Approach to Workflow Management for Scientific Applications". In: *Workflow Management Systems and Interoperability*. Springer, 1998, pp. 145–164. URL: <https://bpt.hpi.uni-potsdam.de/pub/Public/PaperArchive/asi.pdf>.
- [35] Karolina Vukojevic-Haupt, Dimka Karastoyanova, and Frank Leymann. "On-demand Provisioning of Infrastructure, Middleware and Services for Simulation Workflows". In: Proceedings of the 6th IEEE International Conference on Service Oriented Computing & Applications (SOCA 2013). 2013. URL: ???.
- [36] Karolina Vukojevic-Haupt et al. "Service Selection for On-demand Provisioned Services". In: 18th IEEE International Enterprise Distributed Object Computing Conference, EDOC. 2014, accepted for publication.
- [37] *Web Services Security: SOAP Message Security 1.1*. Tech. rep. OASIS, Feb. 2006. URL: <https://www.oasis-open.org/committees/download.php/16790/wss-v1.1-spec-os-SOAPMessageSecurity.pdf>.
- [38] Sanjiva Weerawarana et al. *Web Services Platform Architecture*. Prentice Hall PTR, 2005.

Bibliography

- [39] Matthias Wieland et al. "Towards Reference Passing in Web Service and Workflow-Based Applications". In: 13th IEEE International Enterprise Distributed Object Computing Conference, EDOC. 2009, pp. 109–118. URL: <http://www.iaas.uni-stuttgart.de/institut/ehemalige/schumm/INPROC-2009-52%20-%20Towards%20Reference%20Passing%20in%20Web%20Service%20and%20Workflow-based%20Applications%20 - %20Authors%20Postprint.pdf>.
- [40] Benjamin Zimmer. *figurative 'bootstraps'* (1834). The American Dialect Society Mailing List. URL: <http://listserv.linguistlist.org/cgi-bin/wa?A2=ind0508B&L=ADS-L&D=0&P=14972>.

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Declaration of Authorship

I hereby certify that the diploma thesis entitled

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is entirely my own work except where otherwise indicated. Passages and ideas from other sources have been clearly indicated. To date, neither this diploma thesis nor essential parts thereof were subject of an examination procedure. Until now, I don't have published this diploma thesis or parts thereof. The electronic copy is identical to the submitted copy.

Stuttgart, June 26, 2014,

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(Lukas Reinfurt)