UNIVERSITY OF OSLO
Department of Informatics

CloudML

A DSL for model-based realization of applications in the cloud

Master thesis

Eirik Brandtzæg

Spring 2012

CloudML

Eirik Brandtzæg

Spring 2012

Built: 12th March 2012

Abstract

Contents

List of Figures

List of Tables

Preface

Part I

Introduction

Chapter 1

Introduction

Short and sharp

- Main introduction
- Write lastly

Chapter 2

Cloud computing and Model-Driven Artchitecture

In this chapter the essential topics for this thesis is introduced, cloud computing and Model-Driven architecture.

2.1 Cloud computing

Cloud computing is gaining popularity and more companies are starting to explore the possibilities as well as the limitation to the cloud.

Some of the most essential characteristics of cloud computing [8] are:

- *On-demand self-service*: Consumers can do provisioning without any human interaction. On-demand means dynamic scalability and elasticity of resource allocation, self-service means that users does not need to manually do these allocations themselves.
- *Broad network access*: Capabilities available over standard network mechanisms. Supporting familiar protocols such as HTTP/HTTPS and SSH.
- *Resource pooling*: Physical and virtual resources are dynamically assigned and reassigned according to consumer demand. This means users do not need to be troubled with scalability as this is handled automatically.

Provider	**Service**	**Service Model**
AWS	Elastic Compute Cloud	IaaS
AWS	Elastic Beanstalk	PaaS
Google	Google App Engine	PaaS
CA	AppLogic	IaaS
Microsoft	Azure	PaaS and IaaS
Heroku	Different services	PaaS
Nodejitsu	Node.js	PaaS
Rackspace	CloudServers	IaaS

Table 2.1: Common providers available services

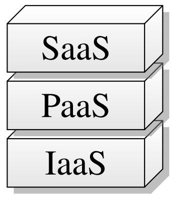


Figure 2.1: Cloud architecture service models

- *Rapid elasticity*: Automatic capability scaling. Already allocated resources can expand to meet new demands.
- *Measured service*: Monitoring and control of resource usages. Can be used for statistics for users but also for cloud services to do on-demand self-service, resource pooling and rapid elasticity.

There are three main architectural service models in cloud computing [8] namely *Infrastructure-as-a-Service* (IaaS), *Platform-as-a-Service* (PaaS) and *Software-as-a-Service* (SaaS). IaaS is on the lowest vertical integration level closest to physical hardware and SaaS on the highest level as runnable applications. Stanoevska-Slabeva [15] emphasizes that *"infrastructure had been available as a service for quite some time"* and this *"has been referred to as utility computing"*, such as Sun Grid Compute Utility.

IaaS. The main providers are Google, Amazon with *Amazon Web Service* (AWS) [1] and Microsoft. A non-exhaustive list of common providers are visualized in TABLE. 2.1. The *National Institute of Standards and Technology* (NIST) is one of the leaders in cloud computing standardization. The NIST Definition of Cloud Computing [8] define IaaS as

> “The capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications.
>
> NIST, 2011

These are capabilities found in cloud provider services, such as AWS *Elastic Compute Cloud* (EC2) and Rackspace CloudServers. NIST continue to state that

> “The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, deployed applications, and possibly limited control of select networking components (*e.g.*, host firewalls).
>
> NIST, 2011

PaaS. The PaaS model is defined as an capability consumers use to deploy applications onto cloud infrastructure that provide fully partially support. For this kind of deployment consumers do not have to manage or control underlying infrastructure capabilities, and in some cases not even configuration. Examples of PaaS providers are Google with *Google App Engine* (GAE) and the company Heroku with their service with the same name. Multiple PaaS providers utilize EC2 as underlying infrastructure, examples of such providers are Heroku Nodester and Nodejitsu, this is a tendency with increasing popularity.

SaaS. The core purpose is to provide whole web applications as services, in many cases end products. Google products such as gmail, Google Apps and Google Calendar are examples of SaaS applications.

There are four different deployment models according to The NIST Definition of Cloud Computing [8]:

- *Public cloud*: Infrastructure is open to the public. Cloud providers own the hardware and rent out IaaS and PaaS solutions to users. Examples of such providers are Amazon with AWS and Google with GAE.
- *Private cloud*: Similar to classical infrastructures where hardware and operation is owned and controlled by organizations themselves. This deployment model has arisen because of security issues regarding storage of data in public clouds. With *private cloud* organization can provide data security in forms such as geographical location and existing domain specific firewalls, and help complying requirements set by the government or other offices.
- *Community cloud*: Similar as *private clouds* but run as a coalition between several organizations. When several organizations share the same aspects of a private cloud (such as security requirements, policies, and compliance considerations), and therefore share infrastructure.
- *Hybrid cloud*: Combining private cloud or community cloud with public cloud. One benefit is to distinguish data from logic for purposes such as security issues, by storing sensitive information in a private cloud while computing with public cloud.

Beside these models defined by NIST there is another arising model known as *virtual private cloud*, which is similar to *public cloud* but with some security implications such as sandboxed network.

2.2 Model-Driven Architecture approach

By combining the world of cloud computing with the one of modeling it is possible to achieve benefits such as improved communication when designing a system and better understanding of the system itself. This statement is emphasized by Booch *et al.* in one of his studies:

> “Modeling is a central part of all the activities that lead up to the deployment of good software. We build models to communicate the desired structure and behavior of our system. We build models to visualize and control the system’s architecture. We build models to better understand the system we are building, often exposing opportunities for simplification and reuse. We build models to manage risk.”
>
> Booch, 2005

When it comes to cloud computing these definitions are even more important because of financial aspects since provisioned nodes instantly draw credit. The definition of “modeling” can be assessed from the previous epigraph, but it is also important to choose correct models for the task. Stanoevska-Slabeva emphasizes in one of her studies that grid computing “*is the starting point and basis for Cloud Computing.*” [15]. As grid computing bear similarities towards cloud computing in terms of vitalization and utility computing it is possible to use the same UML diagrams for IaaS as previously used in grid computing. The importance of this re-usability of models is based on the origination of grid computing, *eScience*, and the popularity of modeling in this research area. The importance of choosing correct models is emphasized by Booch [2]:

> *(i)*The choice of what models to create has a profound influence on how a problem is attacked and how a solution is shaped. *(ii)*Every model may be expressed at different levels of precision. *(iii)*The best models are connected to reality. *(iv)*No single model is sufficient. Every nontrivial system is best approached through a small set of nearly independent models.
>
> Booch, 2005

These definition precepts state that several models (precept *(iv)*) on different levels (precept *(ii)*) of precision should be used to model the same system. From this it is concludable that several models can be used to describe one or several cloud computing perspectives. Nor are there any restraints to only use UML diagrams or even models at all. As an example AWS CloudFormation implements a lexical model of their *cloud services*, while CA AppLogic has a visual and more UML component-based diagram of their capabilities.

Model-Driven Architexture. When working with *Model-Driven Architecture* (MDA) it is common to first create a *Computation Independent Model* (CIM), then a *Platform-Independent Model* (PIM) and lastly a *Platform-Specific Model* (PSM). There are other models and steps in between these, but they render the essentials. There are five different life cycles as explained by Singh [14]:

1. Create a CIM capturing requirements.
2. Develop a PIM.
3. Convert the PIM into PSM.
4. Generate code form PSM.
5. Deploy.

Chapter 3

State of the Art in Provisioning

Evaluation of existing solutions
What have others done for multicloud provisioning
Even more examples in mOSAIC articles

- Identify *properties* (problems in reality)
- Find more sources
- Include more scientific literature!

3.1 Model driven

Amazon AWS CloudFormation http://aws.amazon.com

This is a service provided by Amazon from their popular Amazon Web Services. It give users the ability to create template files in form of JSON, which they can load into AWS to create stacks of resources. This makes it easier for users to duplicate a setup many times, and as the templates support parameters this process can be as dynamic as the user design it to be. This is a model in form or lexical syntax, both the template itself and the resources that can be used. For a company that is fresh in the world of cloud computing this service could be considered too advance. This is mainly meant for users that want to replicate a certain stack, with the ability to provide custom parameters. Once a stack is deployed it is only maintainable through the AWS Console, and not through template files. The format that Amazon uses for the templates is a very good format, the syntax is in form of JSON which is very readable and easy to use, but the structure and semantics of the template itself is not used by any other providers or cloud management tooling, so it can not be considered a multicloud solution. Even though JSON is a readable format, does not make it viable as a presentation medium on a business level.

CA Applogic http://www.3tera.com/AppLogic/

Applogic from CA is a proprietary model based web application for management of private clouds. This interface let users configure their deployments through a diagram with familiarities to component diagrams with interfaces and assembly connectors. This is one of the solutions that use and benefit from a model based approach. They let users configure a selection of third party applications, such as Apache and MySQL, as well as network security, instances and monitoring. What CA has created is both an easy way into the cloud and it utilizes the advantages of model realizations. Their solution will also prove beneficial when conducting business level consulting. They also support a version of ADL (Architecture Deployement Language), a good step on its way to standardization. But this solution is only made for private clouds running their own controller, this can prove troublesome for migration, both in to and out of the infrastructure.

3.2 APIs

libcloud and jclouds http://libcloud.apache.org/ http://www.jclouds.org/

Libcloud is a API that aims to support the largest cloud providers through a common API. The classes are based around "Drivers" that extends from a common ontology, then provider-specific attributes and logic is added to the implementation. jclouds is very similar to libcloud but the API code base is written in Java and Clojure. This library also have "drivers" for different providers, but they also support some PaaS solutions such as Google App Engine. APIs can be considered modelling approaches based on the fact they have a topology and hierarchical structure, but it is not a distinct modelling. A modelling language could overlay the code and help providing a clear overview, but the language directly would not provide a good overview of deployment. And links between resources can be hard to see, as the API lacks correlation between resources and method calls. Libcloud have solved the multicloud problem in a very detailed manner, but the complexity is therefore even larger. The API is also Python-only and could therefor be considered to have high tool-chain dependency.

OPA http://opalang.org/

OPA is a cloud language aimed at easing development of modern web applications. It is a new language, with its own syntax, which is aimed directly at the web. The language will build into executable files that will handle load balancing and scalability, this is to to make this a part of the language and compilation. OPA is a new language, so it might be difficult to migrate legacy systems into this lanugage. There are no deployment configurations, as this is built into the language. The compiler will generate an executable that coWeb-based vs native application

The public cloud is located on the world wide web, and most of the managing, monitoring, payment and other administrative tasks can be done through web interfaces or APIs. Web applications are becoming more popular by the day, with HTML5, EcmaScript 5 and CSS3. The user experience in web applications today can in many cases match native applications, with additional benefits such as availability and ease of use. A web-based interface would prove beneficial for quickly displaying the simple core functionality of the language. In this era of cloud computing and cloud technologies a user should not need to abandon his or hers browser to explore the functionality of CloudML. Cloud providers are most likely to give customers access to customize their cloud services through web-based interfaces, and if customers are to take advantage of CloudML, the language should be graphically integrated into existing tool chains. Providers would probably find it pleasing if a example GUI wauld be run on most cloud providers instances, and so it can also benefit from some cloud based load balancers, even though this is part of the language. The conclusion about OPA is that it is not a language meant for configuration, and could not easily benefit from a model based approach, and it does not intentionally solve multicloud.

Whirr http://whirr.apache.org/
This is a binary and code-based application for creating and starting short-lived clusters for hadoop instances. It support multiple cloud providers. It has a layout for configuration but it is mainly property-based, and aimed at making clusters.

Deltacloud http://incubator.apache.org/deltacloud/
Deltacloud has a similar procedure as jclouds and libcloud, but with a REST API. So they also work on the term "driver", but instead of having a library to a programming language the users are presented with an API they can call, on Deltacloud servers. This means users can write in any language they may choose. As well as having similar problems as other APIs this approach means that every call has to go through their servers, similar to a proxy. This can work with the benefits that many middleware software have, such as cahing, queues, redundancy and transformations, but it also has the disadvantages such as single point of failure and version inconsistencies.

3.3 Deployments

Amazon Beanstalk

simplifying-solution-deployment-on-a-cloud-through-composite-appliances

architecture-for-virtual-solution-composition-and-deployment

Chapter 4

Challenges in the cloud

4.1 Outlined problem

To recognize challenges when doing cloud provisioning an example application [3] was utilized. The application (from here known as *BankManager*) is a prototypical bank manager system which support creating users and bank accounts and moving money between bank accounts and users. *BankManager* is designed but not limited to support distribution between several nodes. Some examples of provisioning topology is illustrated in FIG. 4.1, each example includes a browser to visualize application flow, front-end visualizes executable logic and back-end represents database. It is possible to have both front-end and back-end on the same node, as shown in FIG. 4.1(a). In FIG. 4.1(b) front-end is separated from back-end, this introduces the flexibility of increasing computation power on the front-end node while spawning more storage on the back-end. For applications performing heavy computations it can be beneficial to distribute the workload between several front-end nodes as seen in FIG. 4.1(c), the number of front-ends can be linearly increased n number of times as shown in FIG. 4.1(d). *BankManager* is not designed to handle several back-ends because of relational model based database, this can solved on a database level with master and slaves (FIG. 4.1(e)). Bash-scripts were used to prototype full deployments of *BankManager* against *Amazon Web Services* (AWS) [1] and Rackspace [12] with a topology of three nodes as shown in FIG. 4.1(c). From this prototype it became clear that there were multiple challenges to address:

- **Complexity**: The first challenge encountered was to simply authenticate and communicate with the cloud. The two providers had different approaches, AWS [1] had command-line tools built from their Java APIs, while Rackspace [12] had no tools beside the API language bindings, thus the need of operating both command-line tools as well as public APIs. As this emphasizes the complexity even further it also stresses engineering capabilities of individuals executing the tasks to a higher technical level.

- **Multicloud**: Once able to provision the correct amount of nodes with desired properties on the first provider it became clear that mirroring the setup to the other provider was not as convenient as anticipated. There were certain aspects of vendor lock-in, so each script was hand-crafted for

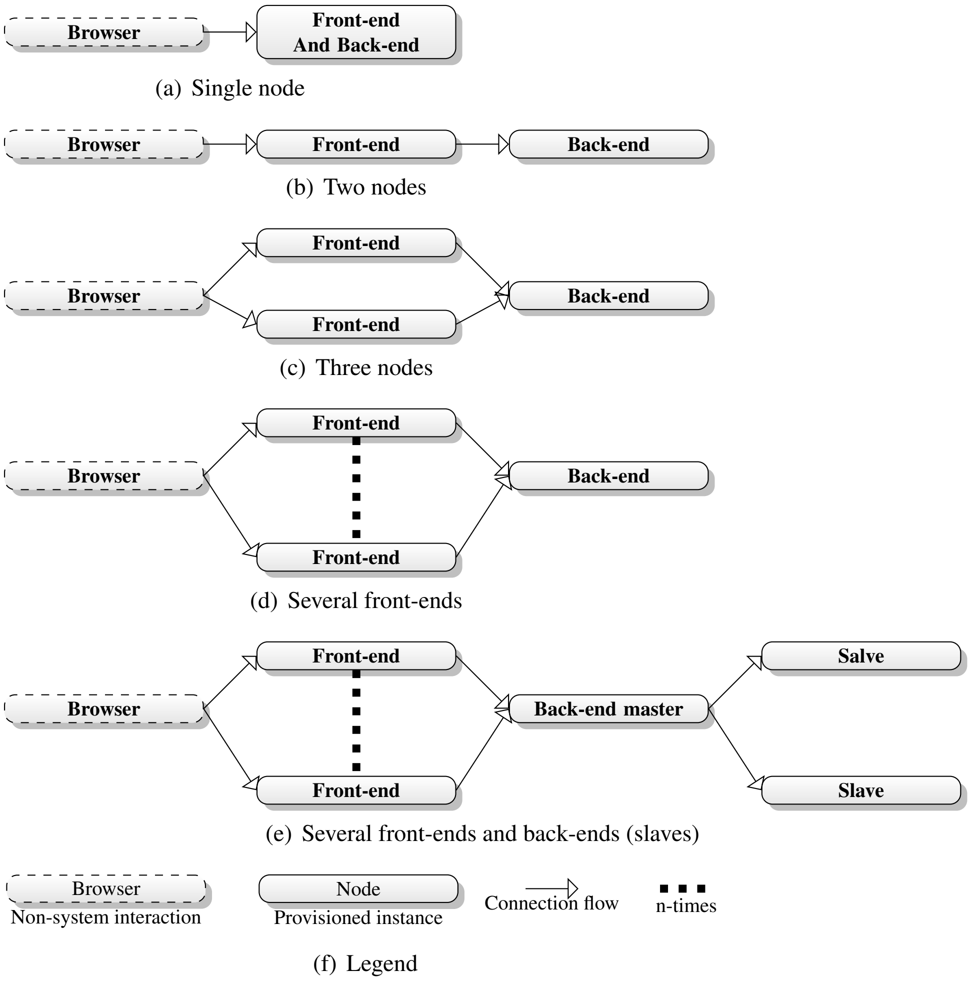


Figure 4.1: Different architectural ways to provision nodes (topologies).

Table 4.1: Analysis

Solution	**Learning curve**	**Business level viable**	**Model driven**	**Multicloud**
Amazon CloudForm-ation	No	Hard	No	No
CA Applo-gic	Yes	Easy	Yes	N
Libcloud	No	Hard	No	Yes
jclouds	No	Hard	No	Yes
OPA	Yes	Hard	No	No
Whirr	No	Hard	No	Yes
Deltacloud	No	Hard	No	Yes
CloudML	Yes	Easy	Yes	Yes

Table 4.2: Analysis

specific providers. The lock-in situations can in many cases have financial implications where for example a finished application is locked to one provider and this provider increases tenant costs. Or availability decreases and results in decrease of service uptime damaging revenue.

- **Reproducibility**: The scripts provisioned nodes based on command-line arguments and did not persist the designed topology in any way, this made topologies cumbersome to reproduce.
- **Shareable**: Since the scripts did not remember a given setup it was impossible to share topologies "as is" between coworkers. It is important that topologies can be shared because direct input from individuals with different areas of competence can increase quality.
- **Robustness**: There were several ways the scripts could fail and most errors were ignored. Transactional behaviors were non-existent.
- **Run-time dependency**: The scripts were developed to fulfill a complete deployment, and to do this it proved important to temporally save run-time specific metadata. This was crucial data needed to connect front-end nodes with the back-end node.

4.2 Why is it important to solve the problems

- Cloud domain is state of the art
- model driven approach with benefits (no special tooling)
- Easier for businesses (especially SMBs) to reach out to Cloud
- Easier for larger more time-constraint businesses to try out the cloud
- Opening the eyes of big providers for a larger cross-cloud language

Chapter 5

Requirements to solution

Model When approaching a global audience consisting of both academics and professional providers it is important to create a solid foundation, which also should be concrete and easy to both use and implement. The best approach would be to support both graphical and lexical models, but a graphical annotation would not suffice when promising simplicity and ease in implementation. Graphical model could also be much more complex to design, while a lexical model can define a concrete model on a lower level. Since the language will be a simple way to template configuration, a well known data markup language would be sufficient for the core syntax, such as JSON or XML.

Multicloud One of the biggest problems with the cloud today is the vast amount of different providers. There are usually few reasons for large commercial delegates to have support for contestants. Some smaller businesses could on the other hand benefit greatly of a standard and union between providers. The effort needed to construct a reliable, stable and scaling computer park or datacenter will withhold commitment to affiliations. Cloud computing users are concerned with the ability to easily swap between different providers, this because of security, independence and flexibility. CloudML and its engine need to apply to several providers with different set of systems, features, APIs, payment methods and services. This requirement anticipate support for at least two different providers such as Amazon AWS and Rackspace.

Executable The language must be dependant of an underlying engine, this is because creating stacks can be in form of a process, and the language should not be an impediment for deployment flows. The engine will not be a part of the PIM version of CloudML, but the language must reinforce this reasoning.

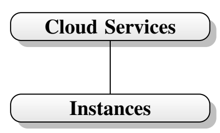


Figure 5.1: Cloud layers

Table 5.1: Requirements

Requirement	Short description	Importance
Lexical model	Language should be based on a lexical model.	3
Graphical model	Lexical model should be represented in diagrams.	2
Multicloud	The language should work against more than one provider.	2
Adaptable (?)	Providers should be able to express what they offer according to the CloudML vocabulary to support automation.	3
Executable	The language will be accompanied by an execution engine able to process it and perform static analysis on a given CloudML file.	x
API	The language should be easy to use through an API.	x
Versoning (VCS)	The lexical language should be easy to maintain in a VCS such as Git, Mercurial or SVN.	x

Table 5.2: Requirements

API The engine underlying CloudML should be easily accessible on a state of the art basis. This is most correctly achieved by implementing an REST based API, which can process CloudML template files correctly.

Versoning The file format should be in such form it can be stored a VCS system such as Git, Subversion or Mercurial. This is important for end users to be able to maintain templates that defines the stacks they have built, for future reuse.

Granularity Cloud computing is often defined into different categories, such as IaaS (Infrastructure as a Service), PaaS (Platform as a Service) and SaaS (Software as a Service), although for CloudML it needs to narrow it down or rather redefine the point of view. The concepts around the language are not defined by what levels of a vendor management responsibilities it should support, but rather more concretely what parts of a system stack that can be configured.

The figure above, Figure 1, show the different layers that CloudML can and should support. The top most level is services that a provider might support, such as CDN, geo-based serving, monitoring and load balancing. All in all services that are external from customers actual application, but that can influence or monitor it. The next level is software, this is for any software that are co-existing with or for the customers application, such as databases, application servers, logging services. All in all software that are running on the same instance as the application, but that the customer would like to have automatically or semi-automatically configured and reconfigured. On the bottom there are two levels, both representing instances. In the instance-level CloudML should bind together instances such as different virtual machines. This level is tightly connected to the Software-layer as connections between instances is very likely to be defined through software, such as , web accelerators and application servers.

Part II

Contribution

Chapter 6

Envision, concepts and principles

The core envision is to tackle challenges from CHAP. 4 by applying a model-driven approach supported by modern technologies. Main objective is to create a common model for nodes as a platform-independent model [9] to justify *multicloud* differences and at the same time base this on a human readable lexical format to resolve *reproducibility* and make it *shareable*.

The concept and principle of CloudML is to be an easier and more reliable path into cloud computing for IT-driven businesses of variable sizes. the tool is envisioned to parse and execute template files representing topologies of instances in the cloud. Targeted users are application developers without cloud specific knowledge. The same files should be usable on other providers, and alternating the next deployment stack should be effortless. Instance types are selected based on properties within the template, and additional resources are applied when necessary and available. While the tool performs provisioning metadata of nodes is available. In the event of a template being inconsistent with possibilities provided by a specific provider this error will be informed to the user and provision will halt.

There are many cloud providers on the global market today. These providers support many layers of cloud, such as PaaS (Platform as a Service) and IaaS (Infrastructure as a Service). This vast amount of providers and new technologies and services can be overwhelming for many companies and small and medium businesses. There are no practical introductions to possibilities and limitations to cloud computing, or the differences between different providers and services. Each provider has some kind of management console, usually in form of a web interface and API. But model driven approaches are inadequate in many of these environments. UML diagrams such as deployment diagram and component diagram are used in legacy systems to describe system architectures, but this advantage has yet to hit the mainstream of cloud computing management. It is also difficult to have co-operational interaction on a business level without using the advantage of graphical models. The knowledge needed to handle one provider might differ to another, so a multicloud approach might be very resource-heavy on competence in companies. The types of deployment resources are different between the providers, even how to gain access to and handle running instances might be very different. Some larger cloud management application developers are not even providers themselves, but offer tooling for private cloud solutions. Some of these providers have implemented different types of web based applications that let end users manage their cloud instances. The main problem with this is that there are no standards defining a cloud instance or links between instances and other services a provider offer. If a provider does not offer any management interface and want to implement this as a new feature for customers, a standard format to set the foundation would help them achieve a better product for their end users. These are some of the problems with cloud hosting today, and that CloudML will be designed to solve.

Chapter 7

Analysis and design - CloudML

7.1 Meta model

The meta model for CloudML is described in FIG. 7.1. CloudML is introduced by using a scenario where "Alice" is provisioning the *BankManager* from CHAP. 4 to AWS *Elastic Compute Cloud* (EC2) using the topology shown in FIG. 4.1(c). It is compulsory that she possesses an AWS account in advance of the scenario. She will retrieve security credentials for account and associate them with `Password` in FIG. 7.1. `Credential` is used to authenticate her to supported providers through `Connector`. The next step for Alice is to model the appropriate `Template` consisting of three `Nodes`. The characteristics Alice choose for `Node` `Properties` are fitted for the chosen topology with more computational power for front-end `Nodes` by increasing amount of `Cores`, and increased `Disk` for back-end `Node`. All `Properties` are optional and thus Alice does not have to define them all. With this model Alice can initialize provisioning by calling `build` on `CloudMLEngine`, and this will start the asynchronous job of configuring and creating `Nodes`. When connecting front-end instances of *BankManager* to back-end instances Alice must be aware of the back-ends `PrivateIP` address, which she will retrieve from CloudML during provisioning according to *models@run.time* (M@RT) approach. `RuntimeInstance` is specifically designed to complement `Node` with `RuntimeProperties`, as `Properties` from `Node` still contain valid data. When all `Nodes` are provisioned successfully and sufficient metadata are gathered Alice can start the deployment, CloudML has then completed its scoped task of provisioning. Alice could later decide to use another provider, either as replacement or complement to her current setup, because of availability, financial benefits or support. To do this she must change the provider name in `Account` and call `build` on `CloudMLEngine` again, this will result in an identical topological setup on a supported provider.

7.2 Actors model

Provisioning nodes is by its nature an asynchronous action that can take minutes to execute, therefore CloudML relied on the actors model [7]. With this asynchronous solution CloudML got concurrent communication with nodes under provisioning. The model is extended by adding a callback-based pattern allowing each node to

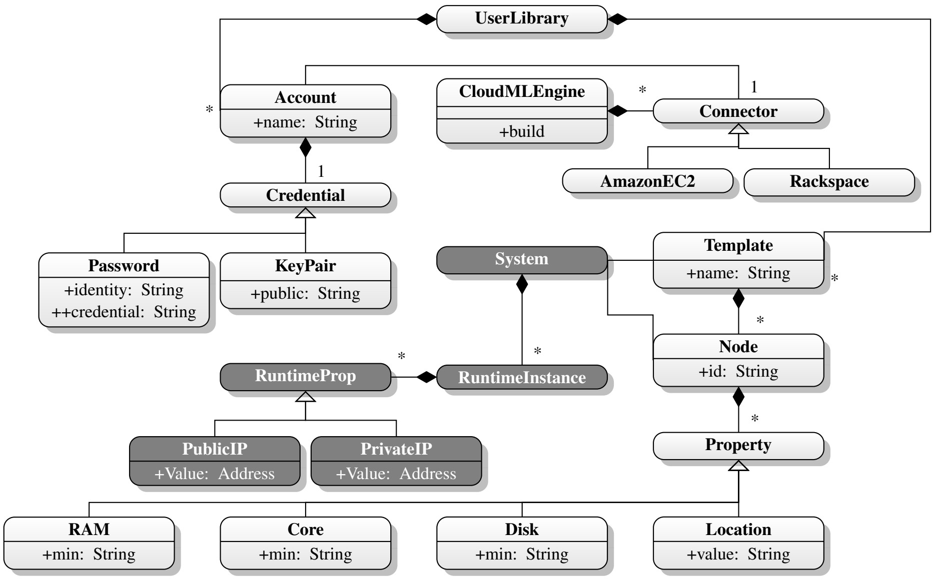


Figure 7.1: Architecture of CloudML

provide information on property and status changes. Developers exploring the implementation can then choose to "listen" for updating events from each node, and do other jobs / idle while the nodes are provisioned with the actors model. The terms are divided for a node before and under provisioning, the essential is to introduce *M@RT* to achieve a logical separation. When a node is being propagated it changes type to `RuntimeInstance`, which can have a different *states* such as *Configuring*, *Building*, *Starting* and *Started*. When a `RuntimeInstance` reaches *Starting* state the provider has guaranteed its existence, including the most necessary metadata, when all nodes reaches this state the task of provisioning is concluded.

Full deployment is planed for next version of CloudML.

Chapter 8

Implementation/realization - cloudml-engine

The envision and design of CloudML is implemented as a proof-of-concept project *cloudml-engine*. The project is split into four different modules (FIG. 8.1). Each module serves a logical task of CloudML. This chapter will go into depths of technologies and structures of the implementation.

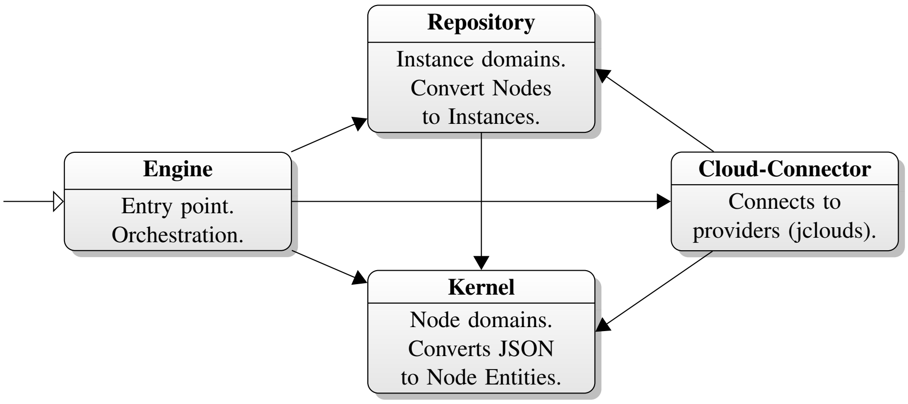
Implementation. CloudML is implemented as a proof of concept framework [4] (from here known as *cloudml-engine*). Because of Javas popularity cloudml-engine was written in a JVM based language with Maven as build tool. Cloudml-engine use jclouds.org library to connect with cloud providers, giving it support for 24 providers out of the box to minimize *complexity* as well as stability and *robustness*.

8.1 Technologies

Cloudml-engine is based on state-of-the-art technologies that appeal to the academic community. Technologies chosen for *cloudml-engine* are not of great importance to the concept of CloudML itself, but it still important to understand which technologies were chosen, what close alternatives exists and why they were chosen.

Language. *Cloudml-engine* is written in Scala, a multi-paradigm JVM based programming language. This language was chosen because JVM is a popular platform, and then especially Java. Scala is compatible with Java and Java can interact with libraries written in Scala as well. The reason not to use plain Java was because Scala is an appealing state-of-the-art language that emphasizes on functional programming which is leveraged in the implementation. Scala also has a built in system for Actors model [7] which is utilized in the implementation.

Lexical format. For the lexical representation of CloudML *JavaScript Object Notation* (JSON) was chosen. JSON is a web-service friendly, human-readable data interchange format and an alternative to XML. This format was chosen because of popularity in the cloud community source? and its usage area as data



(a) Application modules

(b) Legend

Figure 8.1: Architecture of cloudml-engine

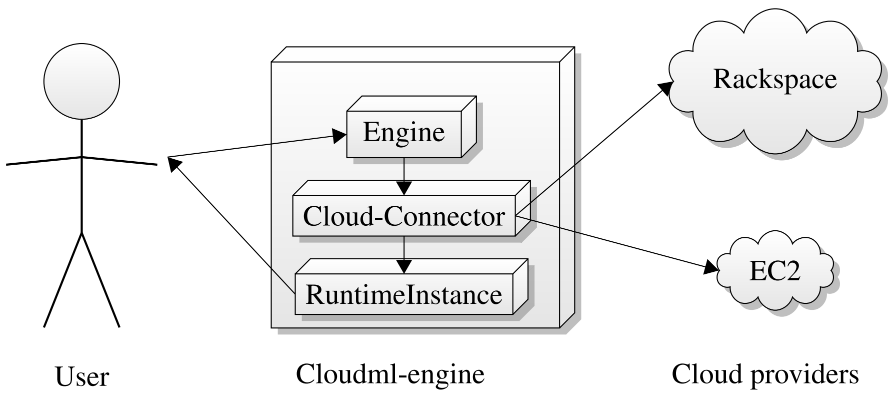


Figure 8.2: Usage flow in cloudml-engine

```xml
<repositories>
 <repository>
  <id>cloudml-engine</id>
  <url>
   https://repository-eirikb.forge.cloudbees.com/release
  </url>
 </repository>
</repositories>
<dependencies>
 <dependency>
  <groupId>no.sintef</groupId>
  <artifactId>engine</artifactId>
  <version>0.1</version>
 </dependency>
</dependencies>
```

Figure 8.3: Example Maven configureation section to include cloudml-engine

```scala
import no.sintef.cloudml.engine.Engine
...
val runtimeInstances = Engine(account, List(template))
```

Figure 8.4: Example Scala callout to *cloudml-engine*

transmit format between servers and web applications. This means *cloudml-engine* can be extended to work as a RESTFul web-service server.

The JSON format is parsed in Scala using the lift-json parser which provides implicit mapping to Scala case-classes. This library is part of the lift framework, but can be included as an external component without additional lift-specific dependencies. GSON was considered as an alternative, but mapping to Scala case-classes was not as fluent compared to lift-json.

Automatic build system. There are two main methods used to build Scala programs, either using a Scala-specific tool called *Scala Build Tool* (SBT) or a more general tool called Maven. For *cloudml-engine* to have an academic appeal it were essential to choose the technology with most closeness to Java, hence Maven was chosen. Maven support modules which were used to split *cloudml-engine* into the appropriate modules as shown in FIG. 8.1. The dependency system in Maven between modules is used to match the dependencies outlined in FIG. 8.1. Parts of a dependency reference in a Maven configuration can be seen in FIG. 8.3, although this is not dependency management in between *cloudml-engine* modules but rather how to add *cloudml-engine* as a dependency itself.

Cloud connection. The bridge between *cloudml-engine* and cloud providers is an important aspect of the application, and as a requirement it was important to use an existing library to achieve this connection. Some libraries have already been mentioned in the *APIs* section in CHAP. 3, of these only *jclouds* is based on Java-technologies and therefore suites *cloudml-engine*. Jclouds uses Maven for building as well, and is part of Maven central which makes it possible to add jclouds directly as a module dependency. Jclouds contains a template system which is used through code directly, this is utilized to map CloudML templates to jclouds templates.

Distribution. *Cloudml-engine* is not just a proof-of-concept for the sake of conceptual assurance, but it is also a running, functional library which can be used by anyone for testing or considerations. Beside the source repository [4] the library is deployed to a remote repository [6] as a Maven module. This repository is provided by CloudBees, how to include the library is viewable in FIG. 8.3.

Actors. As mentioned earlier *cloudml-engine* utilizes the actors model through Scala, this approach is used to achieve asynchronous provisioning. This is important as provisioning can consume up to minutes for each instance. Beside the standard model provided by Scala *cloudml-engine* uses a callback-based pattern to inform users of the library when instance statues are updated and properties are added.

8.2 Modules and application flow

Cloudml-engine is divided into four main modules (FIG. 8.1). This is to distribute workload and divide *cloudml-engine* into logical parts for each task.

Engine. The main entry point to the application, this is a Scala Object used to initialize provisioning. Interaction between `user` and `Engine` is visible in FIG. 8.2 where the user will initialize provisioning by calling `Engine`. `Engine` will also do orchestration between the three other modules as shown in FIG. 8.1. Since `Cloud-Connector` is managed by `Engine` other actions against instances are done through `Engine`. The first versions of *cloudml-engine* did not use `Engine` as orchestrator but instead relied on each module to be a sequential step, this proved to be harder to maintain and also introduced cyclic dependencies.

Kernel. `Kernel` contains CloudML specific entities such as Node and Template. The logical task of `Kernel` is to map JSON formatted strings to `Templates` including `Nodes`. This is some of the core parts of the DSL, hence it is called *`Kernel`*. `Accounts` are separate parts that are parsed equally as `Templates`, but by another method call. All this is transparent for users as all data will be provided directly to `Engine` which will handle the task of calling `Kernel` correctly.

Repository. Has `Instance` entities, these are equivalent to `Nodes` in `Kernel`, but are specific for provisioning. Repository will do a mapping from *Nodes* (including *Template*) to *Instances*. Future versions of `Repository` will also do some logical superficial validation against *Node* properties, for instance at the writing moment it is not possible to demand LoadBalancers on Rackspace for specific geographical locations.

Cloud-Connector. is the module bridging between *cloudml-engine* and providers. It does not contain any entities, and only does logical code. It is built to support several libraries and interface these. At the moment it only implements the earlier mentioned library jclouds.

Chapter 9

Validation & Experiments

- How BankManager proves concepts of the templates (subsection 1) with cloudml-engine

To validate how CloudML addressed the challenges from TABLE. **??** The *BankManager* application were provisioned using different topologies in Fig[4.1(a), 4.1(c)]. The implementation uses *JavaScript Object Notation* (JSON) to define templates as a human readable serialization mechanism. The lexical representation of FIG. 4.1(a) can be seen in LISTING. **??**. The whole text represents the `Template` of FIG. 7.1 and consequently "nodes" is a list of `Node` from the model. The JSON is textual which makes it *shareable* as files. Once such a file is created it can be reused (*reproducibility*) on any supported provider (*multicloud*).

The topology described in FIG. 4.1(c) is represented in LISTING. **??**, the main difference from LISTING. **??** is that there are two more nodes and a total of five more properties. Characteristics of each node are carefully chosen based on each nodes feature area, for instance front-end nodes have more computation power, while the back-end node will have more disk.

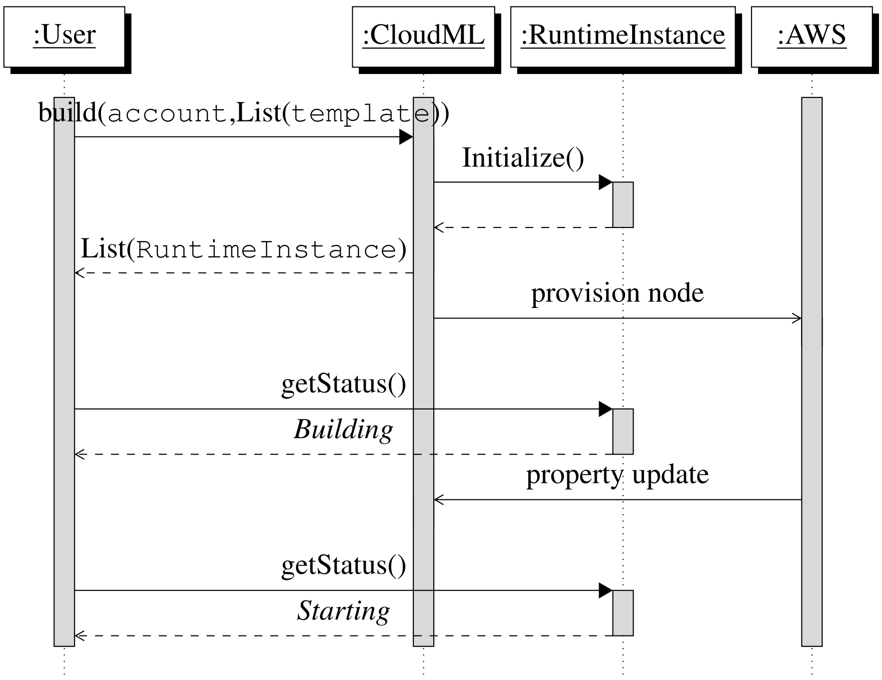


Figure 9.1: Sequence diagram of CloudML.

Part III

Conclusion

Chapter 10

Conclusion

Short and sharp

- Summary of CloudML
  - What subsection in solution solves what subsection in problem
- CloudML
- Implementation
- Perspectives (2 paragraphs, can be section)
  - Look into the future
    - Deployments
  - short term
  - long term

Chapter 11

Related Works

There already exists scientific research projects and technologies which have similarities to CloudML both in idea and implementation. First scientific research projects will be presented with their solutions, then pure technological approaches will be introduced.

One project that bears relations to CloudML is mOSAIC [11] which aims at not only provisioning in the cloud, but deployment as well. They focus on abstractions for application developers and state they can easily enable users to *"obtain the desired application characteristics (like scalability, fault-tolerance, QoS, etc.)"* [10]. The strongest similarities to CloudML are *(i)*multicloud with their API [10], *(ii)*metadata dependencies since they support full deployment and *(iii)*robustness through fault-tolerance. What mOSAIC is lacking compared to CloudML is model-based approach including *M@RT*. Reservoir [13] is another project that also aim at *(iv)*multicloud. The other goals of this project is to leverage scalability in single providers and support built-in *Business Service Management* (BSM), important topics but not directly related to the goals of CloudML. CloudML stands out from Reservoir in the same way as mOSAIC. Vega framework [5] is a deployment framework aiming at full cloud deployments of multi-tier topologies, they also follow a *(v)*model-based approach. The main difference between CloudML and Vega are support of multicloud provisioning.

There are also distinct technologies that bear similarities to CloudML. None of AWS CloudFormation and CA Applogic are *(i)*model-driven. Others are plain APIs supporting *(ii)*multicloud such as libcloud, jclouds and DeltaCloud. The last group are projects that aim specifically at deployment, making *Infrastructure-as-a-Service* (IaaS) work as *Platform-as-a-Service* (PaaS) like AWS Beanstalk and SimpleCloud. The downside about the technical projects are their inability to solve all of the challenges that CloudML aims to address, but since these projects solve specific challenges it is appropriate to utilize them. Cloudml-engine leverages on jclouds in its implementation to support multicloud provisioning, and future versions can utilize it for full deployments.

Chapter 12

Results

Bibliography

[1] Amazon. Amazon web services, 2012.

[2] Grady Booch, James Rumbaugh, and Ivar Jacobson. *Unified Modeling Language User Guide, The (2nd Edition) (Addison-Wesley Object Technology Series)*. Addison-Wesley Professional, 2005.

[3] Eirik Brandtzæg. Bank manager, 2012.

[4] Eirik Brandtzæg. cloudml-engine, 2012.

[5] Trieu Chieu, A. Karve, A. Mohindra, and A. Segal. Simplifying solution deployment on a Cloud through composite appliances. In *Parallel Distributed Processing, Workshops and Phd Forum (IPDPSW), 2010 IEEE International Symposium on*, pages 1 –5, april 2010.

[6] CloudBees. Cloudbees cloudml-engine repository, 2012.

[7] Philipp Haller and Martin Odersky. Actors that unify threads and events. In *Proceedings of the 9th international conference on Coordination models and languages*, COORDINATION'07, pages 171–190, Berlin, Heidelberg, 2007. Springer-Verlag.

[8] Peter Mell and Timothy Grance. The NIST Definition of Cloud Computing Recommendations of the National Institute of Standards and Technology. *Nist Special Publication*, 145(6):7, 2011.

[9] Viet Cuong Nguyen and X. Qafmolla. Agile Development of Platform Independent Model in Model Driven Architecture. In *Information and Computing (ICIC), 2010 Third International Conference on*, volume 2, pages 344 –347, june 2010.

[10] Dana Petcu, Ciprian CrĂČciun, Marian Neagul, Silviu Panica, Beniamino Di Martino, Salvatore Venticinque, Massimiliano Rak, and Rocco Aversa. Architecturing a Sky Computing Platform. In Michel Cezon and Yaron Wolfsthal, editors, *Towards a Service-Based Internet. ServiceWave 2010 Workshops*, volume 6569 of *Lecture Notes in Computer Science*, pages 1–13. Springer Berlin / Heidelberg, 2011.

[11] Dana Petcu, Georgiana Macariu, Silviu Panica, and Ciprian CrĂČciun. Portable Cloud applicationsâĂŤFrom theory to practice. *Future Generation Computer Systems*, (0):–, 2012.

[12] Rackspace. Rackspace cloud, 2012.

[13] B. Rochwerger, D. Breitgand, E. Levy, A. Galis, K. Nagin, I. M. Llorente, R. Montero, Y. Wolfsthal, E. Elmroth, J. Caceres, M. Ben-Yehuda, W. Emmerich, and F. Galan. The Reservoir model and architecture for open federated cloud computing. *IBM Journal of Research and Development*, 53(4):4:1 –4:11, july 2009.

[14] Y. Singh and M. Sood. Model Driven Architecture: A Perspective. In *Advance Computing Conference, 2009. IACC 2009. IEEE International*, pages 1644 –1652, march 2009.

[15] Katarina Stanoevska-Slabeva and Thomas Wozniak. Cloud Basics - An Introduction to Cloud Computing. In Katarina Stanoevska-Slabeva, Thomas Wozniak, and Santi Ristol, editors, *Grid and Cloud Computing*, pages 47–61. Springer Berlin Heidelberg.