Abstract. Since its rise in around year 2008, "Cloud computing" has become a staple buzzword for large business users and scholarly institutions, and has even succeeded in achieving mindshare and penetration into the consumer culture. The technologies and ideas behind it have become applied, though with varying rates of success, and the initial enthusiasm has given way to practical considerations. This trend can be directly observed from comparing the current state of Open source cloud computing projects with their past state. In this paper we present an overview of how Open source cloud computing landscape has changed in the last three years.

Keywords. cloud computing, trends, open source, OpenStack, Nebula, Eucalyptus, OpenQRM, Nebula, mOSAIC, Abiquo, provisioning

1. Introduction

Even though it sometimes might seem that "Cloud computing" is a buzzword which has been with us for a long time, the reality is that the idea first gained popularity around 2008, not even five years from the time this article is written. In this timespan we have seen its rise from a "high-tech" and uncertain technology, to it becoming a "must-have" buzzword in all situations, to its current plateau in which it is a standard technology in the IT infrastructure toolbox for most major companies.

Figure 1: Google trends for "Cloud computing"

The authors of this paper have been involved with various Cloud Computing projects almost throughout the entire time since its rise in popularity, observing and quantifying the quality of Open source Cloud computing projects since 2009, with some ventures into comparing them to commercial offerings. We observe that the trends of maturity and applicability can be described very well by the often-cited bell-curve of idea adoption [15], which can be demonstrated by e.g. comparing them to keyword search trends as shown in Figures 1 and 2. We would like to re-visit the projects we have described previously and express our observations of how they have changed in the course of several years of development.

2. Previous work and paper organization

While there have been a number of papers published on the topics of definition of Cloud computing (such as [2], [4], [5] and [6]), describing what it can be used for (e.g. [7], [8]), the state and applicability of Cloud computing...
In general (e.g. [9], [10]), there is a comparatively significantly smaller number of papers describing the maturity of the technologies and their ecosystems, or comparing the state of Cloud computing today with that of several years ago. Even though there are some claims that the maturation is still pending [11], there is also the beginning of recognition that Cloud computing is indeed becoming (or at least is treated as) a mature technology [12] [13] [14]. This is collaborated by research from Gartner in 2012 (Figure 3) which shows it on the “hype cycle” slope towards disillusionment about its expectations and in the direction of productivity. Based on the developments of the Open source IaaS projects we have tracked, we expect that the figure for 2013 will show Cloud computing significantly advancing in this direction.

After the introduction and previous work sections, this paper will present a short overview of the projects we have tracked in Section 3, give a comparison to their current status in Section 4, provide summary of the state of Open source cloud computing in Section 5, and finally give conclusion and directions for future work in Section 6.


In our earlier work [16] we have described OpenNebula, Eucalyptus, Ubuntu Enterprise Cloud, OpenQRM, Abiquo, RedHat Cloud Foundation Edition One, OpenStack, Nimbus and mOSAIC projects. We will proceed to give very short descriptions of these projects in this section.

OpenNebula\(^1\) is a toolkit for managing data centre infrastructure, and as one of the earliest projects of its kind was not initially created with Cloud computing in mind, calling itself a “virtual infrastructure engine” [17] before “Cloud computing” became a buzzword. It is a mature and popular product with a rapid release schedule, which has released 12 versions in the five years since its first release. The release rate points to OpenNebula being a healthy, continually developed product.

Eucalyptus\(^2\) began as an Open source clone of the Amazon Web Services (AWS) cloud infrastructure, implementing the same APIs and functionalities as Amazon [18]. Its tools and infrastructure can be used to manage private clouds as well as those deployed in the Amazon’s services and a hybrid mixture of the two approaches. Eucalyptus maintains a high level of compatibility with Amazon’s services, which is also formalized in an agreement between Eucalyptus systems and Amazon [19]. It was probably the most popular Open source IaaS system at the time of our first review.

Ubuntu Enterprise cloud (UEC)\(^3\) was the first iteration of Canonical’s Cloud computing efforts. Ubuntu versions 9.10, 10.04 and 10.10 were shipped with Eucalyptus and assorted management tools. While UEC was not a completely new Cloud computing platform, the amount of integration, especially in the area of easy installation, made it an interesting and distinct choice among the IaaS platforms.

OpenQRM\(^4\) is a data-centre infrastructure management solution with strong support managing heterogeneous technologies, intended for small and medium-sized deployments. It has the ability to seamlessly manage both physical and virtual resources, with P2V, V2P and V2V conversion capabilities for virtual machines. It is designed to be extensible and flexible, supporting a wide range of hypervisor products, but at the same time retains a comparatively simple architecture.

Abiquo\(^5\) is an integrated Cloud computing solution for small and medium-sized deployments with an emphasis on business-level concerns such as company-wide policies.

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\(^1\) OpenNebula, http://www.opennebula.org
\(^2\) Eucalyptus, http://www.eucalyptus.com
\(^3\) Ubuntu Enterprise Cloud, http://www.ubuntu.com/cloud/private
\(^4\) OpenQRM, http://www.openqrm.com

In the time since our initial evaluation, we have observed not so much technological changes, as changes in the maturity and expectations from Cloud computing. We will describe how the projects from the previous section changed since our last evaluation.

OpenNebula in 2010 was perhaps the strongest candidate for Cloud computing deployments, with a well-defined and elaborate feature set. In the years 2010-2013, the project has released 7 major versions with a large set of improvements. The amount of progress can be illustrated by the fact that in 2010 significant new features in version 2.0 were the Image Repository which centralizes VM image repository, MySQL support for backend data collection and per-user resource limits (quotas), while in 2012 the version 3.8 brought in the support for Virtual Routers, direct management of VMWare's VMFS volumes (through VMWare's APIs), improvements in providing and consuming EC2 and OCCI (Open Cloud Computing Interface) APIs, as well as user interface improvements (notably, the support for Internet Explorer [20]) – which indicate a shift from completing basic features to polishing a product. Though the project remains strong [21], the Google Trends indicator shows it steadily losing popularity when compared to OpenStack [22].

Eucalyptus started as an Amazon’s EC2 clone and the interoperability with EC2 is still its greatest strength. As one of the Cloud computing pioneers, it is a mature product whose latest version 3.2 was released in December of 2012. However, the pace of publishing new versions is slower than that of OpenNebula, releasing 4 major versions in the period 2010-2013, of which the Open source status of version 3.0 is unclear as it was labeled as "Enterprise edition" [23] and its code is not available in the project’s GitHub repository [24]. Some of the major features introduced in version 3.2 are a web-based graphical user interface (which was missing in previous versions), improved logging capabilities and usage reporting, and support for EMC’s VNX SAN products [25]. In our previous investigation [26], Eucalyptus was ranked relatively close to OpenNebula, but the difference in features has grown since then.

Ubuntu Enterprise Cloud received a complete change of direction, as far as technology is concerned, and has switched from Eucalyptus to OpenStack as its IaaS backbone. This shift may have been caused by Eucalyptus’ partnering with Red Hat and the focus on open source tools, while OpenStack focuses on enterprise-grade solutions. This change in direction is significant, as Ubuntu is a popular operating system for servers and desktops, and the shift to OpenStack may help to increase adoption of the Cloud computing infrastructure.

OpenStack [22] is a set of open source software cloud computing components written in Java and Python targeting the needs of the scientific community, but also trying to find its way into other business use-cases. The components may be used with its own internal IaaS node, but may also be used to manage other IaaS systems via the Amazon AWS/EC2 APIs.

mOSAIC [2] was a project mostly powered by European Union initiatives for technical universities. It was a joint effort of a consortium of European universities from eight countries, which are supposed to collaborate on its execution.

These are the projects we have found to be viable, or to have a viable future, in the Cloud computing arena in the years 2009 and 2010 [16]. The current situation is a bit different, and we will describe it in the next section.
with Red Hat [27], and is possibly related to Eucalyptus dropping Ubuntu as one of its supported operating systems [25]. Since then, Canonical (the company behind Ubuntu) has become a founding member of the OpenStack Foundation [28], with a focus on adding mass-deployment (so-called “MaaS” - Metal as a Service, emphasizing that the hardware is interchangeable) and orchestration features (starting the development of Juju) [29].

OpenQRM remained a comparatively much smaller project than the ones described so far. In the years 2010-2013 it has released 5 new versions, but there have been no releases in 2012. There has so far been one release in 2013, version 5.0, a major refactoring of the system which introduced a number of improvements, including a completely replaced user interface, a new REST API, and the support for PostgreSQL as the database backend. The project is a reasonably good choice for smaller deployments but lacks enterprise-class features [30].

Abiquo was initially an Open source project but has since refocused on commercial support and its source is no longer available. As a consequence, a smaller amount of information on it is available publicly, but available release notes show an increase in available enterprise-class features such as virtual switches, SAN, and VMWare integration [31].

Red Hat’s cloud strategy has become more consolidated and focused. Instead of “Cloud Foundations”, now Red Hat offers concrete products, and a clear path for its customers which starts with virtualization, continues to a Hybrid IaaS solution, and ends with a PaaS solution called OpenShift. Red Hat is leveraging its experience in producing a popular enterprise operating system to integrate Cloud-like functionalities and offer them piecemeal to their customers, in the form of a collection of products.

OpenStack has grown significantly since our last evaluation. The project was started with the Cloud controller and Compute node (called “Nova”, contributed by NASA [33]) and the Object storage node (called “Swift”, contributed by Rackspace [34]), but has since grown to include the Image Service (“Glance” for managing VM images), Identity Service (“Keystone”, for managing users and access rights), Dashboard (“Horizon” offering a Web GUI overview of the cloud), Networking (“Quantum”), Block storage (“Cinder”), with the metering (“Ceilometer”) and Cloud orchestration (“Heat”) components expected in 2013 [35]. The project has thus grown significantly (releasing all four of its official versions in 2010-2012), has collected a huge backing from IT infrastructure companies, and the Google Trends indicator shows it surpassing every other Cloud computing product. Its feature set is growing and is reflecting the competences of the project’s big partners.

Nimbus remains an academic project developed by the University of Chicago, but with a regular release schedule. In the period 2009-2013 there have been eight official releases. However, the project is lacking in “enterprise-class” features, and as an example, the latest version 2.0 implements (among many other features) the support for the qcow2 image format (for the KVM hypervisor), improves basic network configuration, and solves a bug with files larger than 2 GB [36].

The mOSAIC project has released no usable downloads and the development pace seems to be progressing slowly [37]. We consider it unlikely that the project will produce any usable result if continued at this pace, and even if it did, that it will significantly lack in functionalities compared to other, already established projects.

5. The state of Open source IaaS Cloud computing projects

Of the nine Open source IaaS projects we have tracked during the last few years, one can be safely pronounced stalled or even practically without a future (mOSAIC), one has stopped being an Open source project (Abiquo), one underwent an extensive reorganization which took time and effort which were not spent in upgrading the project’s features (OpenQRM) one continued to develop its own portfolio which is, while technically Open source, is not really applicable outside its company's bundle of products (Red Hat Cloud). Of the remaining, one switched direction into committing to completely embracing another project (Ubuntu Cloud), and one is focused on academic applications (Nimbus), leaving three top-tier Open source IaaS projects with general usability: OpenStack, OpenNebula and Eucalyptus.

Of these, OpenStack has achieved the most significant progress, and with it the most exposure and the largest mindshare, which we illustrate with Google Trends results presented in Figure 4. This search trend information was restricted to the time period January 2009-January 2013, and to the “Software” category. Large vendors such as IBM, HP, Cisco, Dell, VMWare and Intel are all either “platinum”-level or “gold”-level members of the OpenStack
Their attraction to OpenStack is in large part due to its modular architecture and reliance on subsystems interacting over a well-defined protocol, which means the companies can easily replace certain components with proprietary, “value-added” parts. The prevalence of OpenStack among Cloud Computing IaaS project is so overwhelming that we observe it could easily lead to a monoculture in the IaaS market.

OpenNebula and Eucalyptus have enough installed user base and recognizability among the technologically savvy that they will continue to exist for some time, but the force of the OpenStack branding will probably result in their slow decline into obscurity.

As the set of features any new product in this category needs to implement to be on-par with these products is large and complex, we consider that the appearance of a new Open source IaaS product in the near future is very unlikely.

6. Conclusion and directions for future work

As the Cloud computing market matures, it is also losing its width and becomes more concentrated into big projects. The introduction of OpenStack was a welcome development as it gathered a large number of IT vendors to agree on a direction, and it is foreseeable that the approaches and APIs created for OpenStack could become a de-facto standard for future Cloud computing systems.

While the projects described in this paper address the IaaS aspect of Cloud computing, it becomes clear that the next direction both for research and practical implementation is in orchestration and provisioning, which we plan to make our next area of research.

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