Creating a unified educational environment for training IT specialists of organizations of the JINR Member States in the field of cloud technologies

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Abstract. Modern science heavily relies on the usage of information technologies (IT). It is important to organize knowledge transfer from IT specialists to non-IT and to less educated and/or skilled IT ones. Nowadays a speed of IT development (as well as achievements of the results these IT are used for) can be sufficiently increased by joining efforts and resources of cooperating organizations, which solve similar tasks. An important aspect of such cooperation is an experience exchange and knowledge transfer, which can be obtained by participating in conferences, seminars, workshops, master classes, etc. That article provides information on the activities around a cloud infrastructure created at the Laboratory of Information Technologies of the Joint Institute for Nuclear Research (JINR). It describes a purpose of its creation, implemented features, use-cases and training events it is used in. A relevance of the JINR and its Member State organizations clouds integration based on the DIRAC middleware is described too. Particular attention is paid to a process of knowledge transfer from JINR colleagues to fellows of other participating institutions through the organizing and holding of seminars, schools, conferences, round tables as well as semestrial training courses for students.

Keywords: Cloud computing, OpenNebula, Virtualization, Virtual machine, Clouds integration, DIRAC, Training, VMware.

1 Introduction

An informatization of the society is a global social process one of the key characteristic of which is that mainstreamed activity in the sphere of social production is data acquisition, accumulation, processing, transfer and usage as well as a production of information with the help of modern computing devices and various means of informational interactions and exchange [1].

Information technologies play an important role in modern science, which is tightly related with a necessity to manage huge data volumes and analyze them.

Apart from other duties the Laboratory of Information technologies (LIT) is responsible for supplying network, computing and storage resources as well as mathematical support for wide range of scientific projects the JINR and its Member State organizations participate in. A hardware support of such LIT's responsibility is realized on the basis of Multifunctional Information and Computing Complex (MICC) [2].

One of the MICC component is a JINR cloud infrastructure [3] (hereinafter referred to as "JINR cloud service", "JINR cloud", "cloud"). It was created in order to manage LIT IT services and servers more efficiently using modern technologies, to increase the efficiency of hardware utilization and services reliability, to simplify access to application software and to optimize proprietary software usage as well as to provide a modern computing facility for JINR users, a local private cloud infrastructure was created. Apart from listed above tasks the JINR cloud resources are actively used for various trainings on grid, cloud and Big Data technologies. More details on that service are provided below.

2 The JINR cloud infrastructure

The LIT JINR cloud is based on OpenNebula software [4]. It consists of the several major components:

- OpenNebula core,
- OpenNebula scheduler,
- MySQL database back-end,
- user and API interfaces,
- cloud worker nodes (CWNs) where KVM-based virtual machines (VMs) or OpenVZ containers (CTs) are running.

A schema of the JINR cloud architecture is shown on the Figure 1.

There are the following types of servers:

- Cloud worker nodes (CWNs) which host virtual machines (VMs) and containers (CTs) are marked on the figure by numeral "1" in a grey square;
- Cloud front-end nodes (CFNs) where all core OpenNebula services including database, scheduler and some other ones are deployed (such hosts are marked on the figure by black numeral "2" inside the same color square);
- Cloud storage nodes (CSNs) based on Ceph SDS for keeping VMs' and CTs' images as well as users' data (marked by black numeral "3" inside the same color square).

Following the OpenNebula documentation recommendations the JINR cloud has odd number of the front-end nodes – three ones which provides a fault-tolerance for 1 node.

All these servers are connected to the same set of networks:

- JINR public and private subnets (they are marked on the figure by blue lines near which the numeral “1” is placed in the same color circle and signed as “JINR pub and priv subnets”);
- An isolated private network dedicated for a SDS traffic (dark green lines with numeral “2” in a circle of the same color and signed as “Priv subnet for storage”);
- Management network (black lines with numeral “3” in a circle of the same color signed as “management subnet”).

Fig. 1. The schema of the JINR cloud Raft HA architecture

All network switches excluding those which are for the management network have 48 ports with 10 GbE each as well as four 40 Gbps SPF-ports for uplinks.

All cloud resources are splitted into few clusters depending on virtualization (KVM or OpenVZ) type and scientific experiment resources are used by. In case of KVM its virtual instance is called “virtual machine” or “VM” whereas in case of OpenVZ it is “container” or “CT”.

The JINR cloud service provides two user interfaces:

- command line interface;
- graphical web-interface (web-GUI) «Sunstone» (either simplified or full-featured one are possible depending on user group he belongs to).

Cloud servers and most critical cloud components are monitored by a dedicated monitoring service based on Nagios monitoring software. In case of any problem with monitored objects a cloud administrators get notifications via email.

The JINR cloud has high availability (HA) setup based on the Raft consensus algorithm [5,6] to provide fault-tolerance and state consistency across its services. According to OpenNebula documentation that consensus algorithm relies on two concepts:

- System State what in the case of OpenNebula-based clouds means the data stored in the database tables (users, ACLs, or the VMs in the system);
- Log what is a sequence of SQL statements that are consistently applied to the OpenNebula DB in all servers to evolve the system state.

To preserve a consistent view of the system across servers, modifications to system state are performed through a special node called the “leader”. The OpenNebula cloud front-end nodes elect a single node to be the leader. The leader periodically sends heartbeats to the other CFNs called followers to keep its leadership. If a leader fails to send the heartbeat followers promote to candidates and start a new election.

Whenever the system is modified (e.g. a new VM is added to the cluster), the leader updates the log and replicates the entry in a majority of followers before actually writing it to the database. It increases the latency of DB operations but enables a safe replication of the system state and the cluster can continue its operation in case of leader failure.

Users are authenticated via ssh protocol on VMs/CTs either with help of their {rsa,dsa}-key or using own Kerberos credentials. Root privileges can be gained with help of sudo tool. The authentication in the cloud web-GUI is based on Kerberos credentials too. SSL encryption is enabled to make more secure information exchange between web-GUI and users’ browsers.

All CFNs and CWNs are connected through 10 GbE network interfaces to the corresponding rack switches which in their turn are connected to the backbone router.

At the moment of writing that article the JINR cloud has about 1600 CPU cores and 8.1 TB of RAM.

Apart from the locally deployed CWNs the JINR cloud has some amount of external resources from the partner organizations of JINR Member State (see below for more details).

3 Ceph-based software defined storage

Another key component of the JINR cloud infrastructure is a software-defined storage (SDS) based on Ceph [7]. It delivers object, block and file storage in one unified system. According to Ceph documentation, each ceph server can play a single or few roles, which are the following:

- Monitor (mon). It maintains maps of the cluster state, including the monitor map, manager map, the OSD map, and the CRUSH map. These maps are critical cluster state required for Ceph daemons to coordinate with each other. Monitors are also responsible for managing authentication between daemons and clients. At least three monitors are normally required for redundancy and high availability;
- Manager (mgr). It is responsible for keeping track of runtime metrics and the current state of the Ceph cluster, including storage utilization, current performance metrics, and system load. The Ceph Manager daemons also host python-based plugins to manage and expose Ceph cluster information, including a web-based dashboard and REST API. At least two managers are normally required for high availability;
- Object storage daemon (OSD). It stores data, handles data replication, recovery, re-balancing, and provides some monitoring information to Ceph Monitors and Managers by checking other Ceph OSD Daemons for a heartbeat. At least 3 Ceph OSDs are normally required for redundancy and high availability;
- Metadata Server (MDS). It stores metadata on behalf of the Ceph Filesystem. Ceph MDSs allow POSIX file system users to execute basic commands (like ls, find, etc.) without placing an enormous burden on the Ceph Storage Cluster.

Apart from these daemons, there is RADOS gateway (RGW) which provides interfaces for interacting with the storage cluster.

The JINR Ceph-based SDS deployment schema as well as each server roles are shown on the Figure 2.

Fig. 2. The schema of the Ceph-based software-defined storage deployed at LIT JINR

At the moment of writing that article total amount of raw disk space in that SDS is about 1 PB. Due to triple replication, an effective disk space available for users is about 330 TB.

4 Clouds integration

A necessity to process and analyze huge data volumes as well as a lack of computing and storage resources in a single place for such kind of tasks led to development of worldwide distributed information and computing infrastructures which integrates resources all over the world.

The JINR also participates in the large number of research projects in many of which computing infrastructures play important role in obtaining meaningful scientific results.

In that connection, an integration of JINR Member State organizations resources in uniform distributed information and computing environment (DICE) is an important and topical task, the solution of which would significantly accelerate a scientific research [8].

Each organization participating in joining its local computational resources created or being creating a private cloud infrastructure for effective utilization of resources.

Initially a driver for clouds integration following so called “cloud bursting” model [9] was developed by the fellows of the LIT JINR. That driver had been successfully used during several years as a tool for joining clouds from such the JINR Member State organizations as Plekhanov Russian University of Economics (Moscow, Russia), Bogolyubov Institute for Theoretical Physics (Kiev, Ukraine) and the Institute of Physics of the National Academy of Sciences of Azerbaijan (Baku, Azerbaijan).

A scheme of the clouds integration following the “cloud bursting” model is shown on the Figure 3, left.

Fig. 3. Two schemas of clouds integration: 1) using cloud bursting driver (left) and 2) using DIRAC interware (right)

Enormous interest of the JINR Member States in the uniform distributed computational environment has led to the growing number of its participants. That revealed a low scalability of approach used due to sufficiently increased complexity of such infrastructure maintenance (every new cloud integration requires changes in configuration files of every integrated cloud as well as appropriate services restart). That is why research work was started to evaluate possible alternatives.

Among existing software platforms for distributed computing and data management a DIRAC (Distributed Infrastructure with Remote Agent Control) [10] one was chosen because of the following reasons:

- it provides the whole needed functionality including both job and data management;
- cloud as a computational back-end support (although an appropriate plugin required some development);
- easier services deployment and maintenance in comparison with other platforms with similar functionality (e.g. EMI).

A schema of clouds integration using DIRAC grid middleware is shown on the Figure 3, right.

Such approach also allows to share resources of each cloud between external grid users and local non-grid ones.

The services of the DIRAC platform itself are deployed in the JINR cloud, which, together with the clouds of the organizations of the JINR Member States, provides computing resources for the grid environment.

DIRAC is a software framework for distributed computing providing a complete solution to one (or more) user community requiring access to distributed resources.

DIRAC builds an intermediate layer between the users and the resources offering a common interface to a number of providers of heterogeneous resources.

The Workload Management System with Pilot Jobs introduced by the DIRAC project is now widely used in various grid infrastructures. This concept allows one to aggregate in a single system the computing resources of different source and nature, such as computational grids, clouds or clusters, transparently for the end users.

Unlike the “cloud bursting” model, the DIRAC platform allows one to use different computing resources with the help of pilot tasks.

There is already built-in mechanism in DIRAC for interaction with clouds, which is based on the usage of one of the implementation of Open Cloud Computing Interface (OCCI) – for example rOCCI, which is ruby-written one. Since clouds integration with help of cloud bursting driver also relied on the utilization of rOCCI-servers locally deployed at each partner cloud then adding clouds into DIRAC-based infrastructure required much less extra efforts.

Due to pretty limited set of operations client is capable to perform with a cloud via rOCCI it was decided to develop DIRAC module (named “VMDIRAC”) which should be able to interact with OpenNebula-based clouds using their native XML-RPC API.

Such module was developed [11] and successfully validated for usage in production DIRAC release.

In order to test the possibility of such use of cloud resources, a series of tests were conducted, which resulted in new virtual machines that were successfully created, their contextualization was performed, user tasks were started, and the results were sent to the storage element. No special actions were required to run tasks on different cloud resources. At the moment, the program code of DIRAC is being finalized, because not all the necessary functionality is present in the basic version of the system.

At present, the integration of the JINR Member State organizations clouds into DIRAC-based distributed platform is at different stages. Their technical integration has been fulfilled, work on testing and debugging is in progress for the Astana branch of the Institute of Nuclear Physics — the private entity “Nazarbayev University Library and IT Services” (Astana, Kazakhstan) [12], the Scientific Research Institute for Nuclear Problems of Belarusian State University (Minsk, Belarus), Yerevan Physical Institute (Yerevan, Armenia), the Institute of Physics of the National Academy of Sciences of Azerbaijan (Baku, Azerbaijan), and Plekhanov Russian University of Economics (Moscow, Russia). In the process of integration are the clouds of the Institute for Nuclear Research and Nuclear Energy of BAS (Sofia, Bulgaria), Sofia University “St. Kliment Ohridski” (Sofia, Bulgaria), Georgian Technical University (Tbilisi, Georgia),

and the Institute of Nuclear Physics (Tashkent, Uzbekistan). Negotiations are in progress with the University “St. Kliment Ohridski” (Bitola, Macedonia). Figure 4 maps the location of the organizations listed above.

Fig. 4. The geographical location of cloud infrastructures of organizations from JINR Member States involved in the integration of cloud resources.

5 Training

Trainings on how to build local cloud or grid infrastructures, integrate them into distributed environment and use them for own purposes are held on a regular basis or upon requests from the JINR Member State organizations.

A set of training events was organized and conducted for specialists from various countries in creating cloud platforms based on OpenNebula and using resources of distributed information and computing environments (the information on conducted trainings are shown in the table 1).

The purpose of the training courses is to provide information to university students, employees of various organizations in the form of easy-to-understand and use in their everyday needs, both personal and organizations.

The training includes the following aspects:

- providing information about the main cloud services;
- providing information on the use of virtualization, advantages and disadvantages;
- hands-on tutorial with access to cloud infrastructures and the opportunity to get practical experience in VM management: its creation, deployment, suspending, resuming, making VM disk snapshots, terminating, etc).

Table 1. The information on conducted trainings.

Organization/Event	Organization location	Training dates	Number of trainees	Training type	Training location
Internship of specialists from Uzbekistan	Uzbekistan	08.06-06.07.2018	2	usage and administration	JINR, Dubna, Russia
Internship of young scientists from CIS countries	CIS countries	24.05.2018	20	usage	JINR, Dubna, Russia
The course of cloud services and virtual environments	Dubna University, Dubna, Russia	01.09.-29.12.2017	22	usage	Dubna University, Dubna, Russia
Internship of young scientists from CIS countries	CIS countries	17-18.07.2017	6	usage	JINR, Dubna, Russia
L.N. Gumilyov Eurasian National University	Astana, Kazakhstan	22.07.2017	5	usage	JINR, Dubna, Russia
Kazakhstan, Georgia, Bulgaria scientific organizations	Kazakhstan, Georgia, Bulgaria	05-09.06.2017	7	usage and administration	JINR, Dubna, Russia
Internship of young scientists from CIS countries	CIS countries	02.11.2016	20	usage (demo)	JINR, Dubna, Russia
Institute for Nuclear Problems of Belarusian State University	Minsk, Belarus	31.10-03.11.2016	3	usage and administration	JINR, Dubna, Russia
Grid'2016 school	JINR	05.07.2016	5	usage	JINR, Dubna, Russia
Egyptian scientific organizations	Egypt	06-08.06.2016	4	usage	JINR, Dubna, Russia
Institute of Experimental and Applied Physics, Czech Technical University	Prague, Czech Republic	07-10.07.2015	2	usage	JINR, Dubna, Russia
Egyptian scientific organizations	Egypt	05-09.06.2015	3	usage	JINR, Dubna, Russia
JINR	Dubna, Russia	26-27.01.2015	11	usage	JINR, Dubna, Russia
Gdansk university of technologies	Gdansk, Poland	06.10-12.12.2014	1	usage and administration	JINR, Dubna, Russia

The Joint Institute for Nuclear Research is actively working on the organization and conduct of schools, conferences, round tables, schools at conferences.

From 2010 to 2016, under support of the Institute, the AIS-GRID information technology school “GRID and administrative and management systems of CERN” had been held annually [13-19]. The aim of the school was to acquaint students with issues of managing complex scientific complexes and information systems in such areas as web, grid technologies, distributed, cloud computing, administrative information systems. Leading specialists from JINR and CERN gave lectures during AIS-GRID schools.

From September 25 to 29, 2017, Montenegro, Budva the 2nd International School on Heterogeneous Computing Infrastructure within the framework of the XXVI International Symposium on Nuclear Electronics and Computing NEC’2017 was held [20]. The main topics of the school conference were big data analytics, distributed and cloud computing, high-performance and high-speed computing systems, machine learning. The school was attended by leading scientists from Russia, USA, Italy, UK, JINR staff, SIC KI, CERN and DESY.

From September 10 to 14, 2018 at the Laboratory of Information Technologies (LIT) of the Joint Institute for Nuclear Research (JINR), Dubna in frames of the Conference “Distributed Computing and Grid-technologies in Science and Education” International school “Scientific computing, Big Data analytics and machine learning technology for megascience projects” was held [21]. The aim of the school was to attract young scientists, graduate students and students to solve IT problems related to various aspects of megaprojects in the field of high-energy physics, as well as acquaintance with modern methods of big data analytics, machine learning technologies on high-performance computing systems used to solve these problems. The proposed lecture and training program of the School allowed participants to familiar with all aspects of research related to big data using the example of the NICA mega-project and experiments at the Large Hadron Collider as the main sources of big data in high-energy physics. Within the school, training courses are organized on distributed systems for collecting, processing, managing and storing information; the use of high-performance and high-speed computing systems (supercomputers, computer clusters, cloud computing) for processing and modeling data from physical experiments, including methods of machine learning. The school participants had the opportunity to listen to the plenary reports of leading world scientists and specialists in the field of grid technologies and distributed computing presented at the GRID’2018 conference.

From 24 to 26 September 2018, Baku hosted the “International Conference and School dedicated to the 100th anniversary of Academician G. B. Abdullayev” [22]. The school program covered various aspects of information technologies applications in such areas as solid-state physics, high-energy physics, nuclear physics, mathematics, particle detectors and photoconverters, virtual learning systems.

In addition to organizing schools and conferences, LIT has tight cooperation with universities from Russia and other JINR Member States. Especially close cooperation with the University “Dubna”, where the laboratory staff conduct semester courses in various areas of information technology, including such courses as “Distributed computing and cloud technologies”, “Cloud services and virtual environments”.

As part of these courses, students are introduced to the concepts of "distributed computing", "cloud technologies", and the main cloud services:

- SaaS (Software as a Service) - applications running in the cloud, access to which end users receive through a web interface;
- PaaS (Platform as a Service) - a set of tools and services that facilitate the development and deployment of cloud applications;
- IaaS (Infrastructure as a Service) - computing infrastructure (servers, data storage, networks, operating systems), which is provided to customers to run their own software solutions.

The advantages and disadvantages of each service learn the basics of virtualization, work with different hypervisors (VMware, KVM). Students use various cloud-based software during the learning process, from personal use programs to creating their own virtual machine in the cloud. University students have the opportunity to work both in the JINR cloud, creating virtual machines based on OpenNebula open source software, and in the university cloud, creating virtual machines based on the Virtual Computing Laboratory platform.

The Dubna University's Virtual Computing Lab software platform is based on VMware vSphere software, which consists of vSphere ESXi hypervisors with specific enhancements and optimizations for specific hardware that process all virtual machine computing work, as well as vCenter Server central management servers.

The vCenter Server consists of the following key components:

- vCenter Single Sign-On. This component is critical to the whole environment, since it provides secure authentication services for many vSphere components. Single Sign-On creates an internal secure domain in which the various components and solutions that are included in the vSphere ecosystem are registered during the installation or upgrade process, and subsequently they will be assigned basic infrastructural resources. Within the VCL architecture this component is responsible not only for internal authentication services, but it is also used to authenticate users from the university's internal domain who have Microsoft Active Directory accounts at the university.
- vCenter Server. The vCenter Server component is a central component that is used to manage the vSphere environment. This module provides management and monitoring interfaces for a number of vSphere nodes, and it also enables the use of such technologies as VMware vSphere vMotion and VMware vSphere High Availability.
- vCenter Inventory Service. Approximately ninety percent of vSphere Web Client requests to the server are just requests to read the current configuration of the system and its state. The Inventory Service is a component that caches most of the information about the current state of the environment in order to respond to vSphere Web Client requests thus reducing the load on vCenter basic processes.
- vSphere Server for Web Client (vSphere Web Client). vSphere Web Client is the main interface that is used to manage the environment in centralized manner. It can be divided into two parts: the first server part which serves requests from the second part which is the end user's Adobe Flex compatible browser with support for NPAPI-

plugins. It is worth noting that the VCL may also be managed using the vCenter Server Desktop Client that is installed on the end user's computer.

- vCenter Server Database. The database is one of the key modules in the vCenter Server stack architecture. Almost every request sent to the vCenter Server entails communicating with the database. This database is the main storage location for vCenter Server parameters, and it is also a repository of statistical data. Saved statistical data make it possible to optimize system performance during subsequent analysis.
- The NVidia Kepler graphics card is used for 3D virtualization, and VMware Horizon Suite is used for remote VDI connections as well as for creating images of virtual servers and workstations that are separated into layers using VMware ThinApp and for managing these images. This solution is very important for machine learning due to a significant increase in the speed of learning of neural networks.

A centralized management portal as well as a knowledge management system were created in order to manage the virtual computer laboratory. The need to create such a system was conditioned by the fact that students are able to learn about distributed information systems remotely, so it is important to create a social network between all participants as well as to create an environment that provides for pupils the opportunity to independently engage in such processes as the identification, acquisition, presentation, and use (distribution) of knowledge without the direct involvement of the instructor [23-31].

6 Conclusion

When working at a research institute and developing new technologies, it is imperative that you pass on your knowledge, since the exchange of experience is one of the engines of progress. Attending conferences, organizing round tables, conducting and attending seminars and master classes is a necessary criterion for the successful development of an organization. Conducting courses at universities, in turn, not only improves the level of theoretical and practical knowledge of students, but also prepares qualified future personnel for the further development of information technology.

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