Infrastructure for Data Storage and Computation in Biomedical Research

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Summary

Infrastructure as a service (infrastructure which is offered to customer in the form of service of the provider) is a deployment model which allows utilize data and computing capacity of a cloud as a set of virtual devices and virtualized machines. Infrastructure as a service can be offered separately to each project. The same capacity of connected physical machines and devices can be shared. Currently, the concept of an Infrastructure as a service is tested on several projects within activity of the CESNET association, First Faculty of Medicine, Charles University, Prague and Musical and Dance Faculty of Academy of Performing Arts in Prague.

The current research in the field of computation physiology is demanding on a high computation capacity. The computation tasks are distributed to computers, which are provided by the infrastructure. The project in the field of the analysis of a human voice is demanding on high throughput of a computer network between an acoustic or video device on the local side and an analytic application on the remote high performance server side. This paper describes features and main challenges for infrastructure dedicated for such a type of an application. Infrastructure as a deployment model of cloud computing might be beneficial for a multi domain team and for collaboration and integration of a high specialized software application.

Keywords: cloud computing, infrastructure as a service, virtualization, computation physiology, identification of physiological systems, validation of physiological models, remote desktop protocol, grid computing, voice range profile

1. Introduction

Several tasks can be found in the field of an application dedicated to support biomedical research of the current distributed computing systems. The main tasks cover exchanging, storing and retrieving data. The other task is to support the analysis of data and allow long lasting parallel computation. The requirement to keep privacy of patients data is the important feature of these systems and thus it must be ensured that only authorized users may access to application and data. The high level of security is a must, or an appropriate anonymization should be implemented.

Systems focused on data exchange among different organizations try to optimize data flow via the computer network, they encrypt the data which are sent via the network, ensure the required level of reliability and integrates several incompatible systems.

The first example of distributed systems are PACS (Picture Archiving and Communication Systems). DICOM (Digital Imaging and Communications in Medicine) is the most often used standard of format and protocol to exchange medical imaging information in the field of radiology. The security of transfered images is kept on other levels of the system. PACS systems are built upon the DICOM and solves the storage and maintenance of medical images. These systems are mainly deployed and closed within a hospital or within a network of hospitals maintained by the same owner. There became a requirement to join these PACS systems from different locations. Although the DICOM protocol is used, PACS systems have proprietary implementation of management and maintenance of DICOM images and there appeared an issue caused by incompatibilities of PACS systems.[1]. There were introduced systems for exchanging DICOM, which followed the classical structure of central storage and distributed user access (e.g. MeDiMed)[2]. There were introduced systems built as a communication centers with ability to send data among the different PACS systems (e.g. ePACS[3] or ReDiMed).

The project R-Bay was the another example of distributed systems for medicine. There were researched the possibilities how to join general systems, including exchange of DICOM images among institutions from different European countries. There was researched also the ability to provide and consume services of radiologists remotely on an international level. [4]

The systems which use computation and/or data grid is the other example of the distributed system in medicine. The project Globus Medicus is built upon the grid middleware Globus Toolkit. It provides services which presents a the DICOM interface to the user. The usage of grid middleware brings some beneficial features like reliability, security and effective transfer of data [5].

The system built within the project FONIATR is an example of the system demanding on the data transfer rate. This system supports a phoniatric examination and provides an application for the analysis of the human voice over the remote desktop protocol (RDP) in the MS Windows platform [6].

The system built within the project IDENTIFIKACE is an example of the computation system. Computational models of human physiology are developed in the MATLAB/Simulink environment and the new models also in the Modelica language [7]. Current models cover the whole complex functional parts of human physiology and reuse published relations and schema [8]. The models are validated against the data measured on patients within the project work, this is so-called identification of physiological systems. Some of the model parameters cannot be measured thus they are estimated by optimization techniques, which are demanding on performance and take a lot of a computational time. The estimation of parameters may take several hours or days on some more complex models. There are developed techniques to parallelize the computation and distribute the computation tasks to desktop computers in the laboratory or computers in the academic grid centers [9].

It's possible to built an own infrastructure for each of the previously mentioned systems. This may be, however, demanding on money, time and human resourcess when purchasing, installing and configuring all the needed servers and devices.

2. Methods

The infrastructure provided in an academic environment in the form of shared computational and data clusters is one of the way how to streamline the process of building up the computational and data resources. This possibility is offered by a national or international computational and data grid. Some of the projects may require a specific environment or a specific version of software library, which is not present in general grid systems. This requirement might be solved by using virtualization and cloud computing.

Computation and data grid

The computational grid is a hardware and software infrastructure that provides dependable, consistent, pervasive, and inexpensive access to high-end computational capabilities [10]. Data grid may be characterized as an integrating architecture to do an efficient and reliable execution of data queries, which requires careful management of terabyte caches, gigabit per second data transfer over wide area networks, coscheduling of data transfer and supercomputer computation, accurate performance estimations to guide the selection of data replicas and other other advanced techniques that collectively maximize use of scarce storage, networking and computing resources [11].

It needs an additional effort to administer and maintain the grid infrastructure. This task is typically provided by a national grid initiative and the grid infrastructure is shared among different independent users. The national grid initiative was established in the Czech Republic and is maintained by the METACENTRUM activity which is one activity of the NREN (national research and educational network) provider, the CESNET association [12] and coordinates also the work with NGI from neighboring countries in the European Grid Initiative (EGI).

The system needs to be customized and use the API provided by the grid middleware Globus Toolkit, gLite and others.

Desktop grid

Anybody (from the academic and research community) can join and use the grid built by the NGI. Usually only the provider of NGI maintains and enlarges this infrastructure and grid middleware.

There exists different concepts how to built the grid. Everybody can enlarge the grid infrastructure by joining their computer and decides which application can use their computer for computation. The most well known example of such a grid system is SETI@home [13]. The concept of SETI@home follows the idea that anyone connected to Internet can join a grid by downloading a small client program and execute it in the background which periodically asks for computational jobs and computes in the background or as a screen-saver. The grid nodes are typically PCs owned by individuals. Such systems are usually referred as Volunteer grid systems or Desktop Grids and a general desktop grid system BOINC is used to build such systems, customized server site and client application to form a custom desktop grid application[14], [15].

Cloud computing

Virtualization is a technology which provides separation between a software layer and an underlying hardware layer. It allows execution of one of more so-called virtual machines sharing one physical hardware. The virtual machine is fully or partly (paravirtualization) separated from the physical layer of the hardware and thus different platforms (Windows, Linux) may work together on one physical machine concurrently. Virtualization techniques introduce some overhead when translating an isolated application instruction to the lower level of a system. However, the open source paravirtualization system XEN does not impose an onerous performance penalty comparing to non-virtualized operating system configuration [17].

The virtualization is sometimes charaterized as a key technology which enables cloud computing and execution of different isolated systems on shared hardware.

Virtual infrastructure

Virtual organization is a group of users, who share the same resources. The virtual infrastructure belonging to a virtual organization is built from virtual machines connected via the network, which may be virtual too and accessible only to users from the virtual organization. Figure 1 shows an example of several virtual organizations and their infrastructures. On the right part there is a schematic view on physical connections among different organizations (hospitals, research institutions) via the academic network or the Internet. The physical resources are shown as vertexes and network connections are shown as edges. Each cloud shows one virtual infrastructure. On the left part there is a physical server executing more virtual machines, each machine belongs to a different virtual infrastructure.

3. Results

The pilot infrastructure dedicated for the medical application was established within the CESNET's activity "Application support" in several locations in Prague. It utilizes the open-source virtualization system XEN and tools of the operating system Linux for configuring virtual machines and virtual infrastructure as a service.

The instance of the grid system Globus MEDICUS was the primary system deployed to a set of virtual machines. It was shown that the grid system based on open standards can be easily integrated with current medical systems using the DICOM format [18].

The application to support a phoniatric examination was deployed next to the previous system to exchange medical images. It was needed to develop an enhancement of the RDP protocol, which adds the transfer of an audio signal from local computer's microphone to the remote application [6]. This system is currently deployed on one virtual machine. See Figure 2.

The pilot infrastructure contains also the system for identification of physiological systems, which offers a web service distributing the computational task to desktop computers connected via the desktop grid system BOINC and SZTAKI Desktop Grid API [9]. The schema in Figure 3 shows the architecture of the system. The server is in operation as an independent virtual machine and contains the web service. Some of the BOINC workers are in operation as independent virtual machines deployed on less used physical servers of the pilot infrastructure. Some of the desktop computers of laboratory and classroom of the First Faculty of Medicine are connected to this desktop grid system. Other computers may be easily joined. Current research is focused on the possibility to enhance the computational capacity of the infrastructure by the resources provided by the NGI MetaCentrum. There is also researched an utilization of GPU computing.

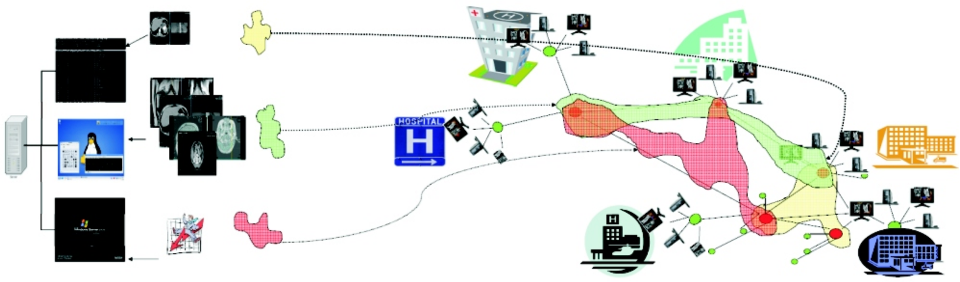

Fig. 1. General schema of virtual infrastructure.

All the physical servers of the pilot infrastructure have a virtual environment built upon the XEN system and they share the IP network addresses. Each virtual machine has its own disk partition within the Logical Volume Management (LVM) on the physical server. The virtual machines are administered by the tool virt-manager and the network environment is configured with the tool iptables.

4. Discussion

The pilot infrastructure can be characterized as a private cloud, which is accessible only to the limited community of users from the field of biomedical research. Virtual machines share the physical network connection via IPv4. Because of the lack of numbers of unique IPv4 addresses, the configuration of network services (webserver, RDP) is realized using network address translation and port mapping. If the network devices passed to the version 6 of IP protocol, there would be opened again the possibility to provide unique IP addresses to virtual machines and there would not be needed extra configurations of network address translation and port mapping.

There are not used special tools to administer cloud within the pilot infrastructure, because the number of projects is relatively small currently. Anyway, there exist free or commercial products (Eucalyptus, OpenNebula, VMWare vSphere), which provide a set of tools to automatize the maintenance of private cloud, including virtual network configuration, live migration of virtual

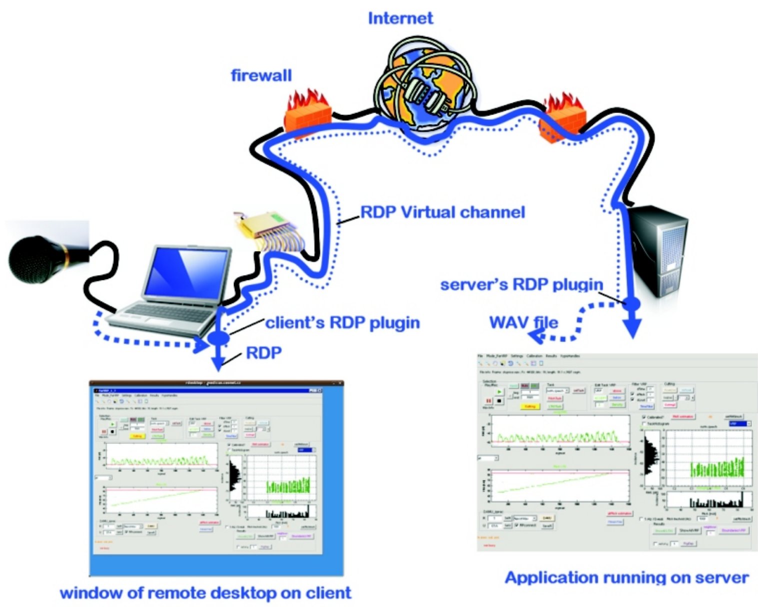

Fig. 2. Schema of system for human voice analysis and remote recording via RDP protocol.

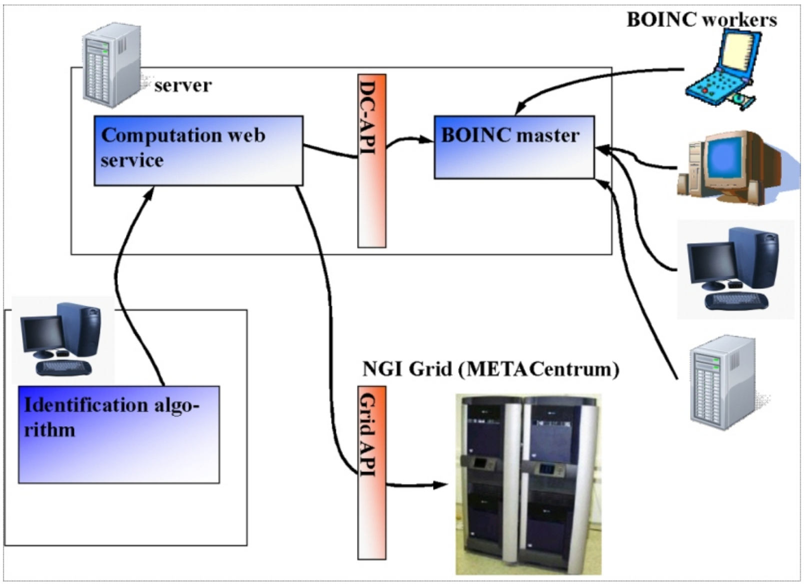

Fig. 3. Schema of computational infrastructure for identification of physiological systems.

machine, etc. Deploying these tools will be necessary in future after expected enhancement of the physical capacity, which is planned to be built within the academic environment of the Czech Republic.

The important question is: which type of the application is suitable for clouds operating on physical resources spread in different geographical locations compared to clouds operating in supercomputing centers. Clouds in supercomputing centers are suitable for highly parallel tasks which need fast communication between parallel computational tasks. Cloud operating on physical servers in different geographical locations can offer a free capacity in the time period, when the owner does not utilize its physical resources and offers them to other users of cloud.

5. Conclusion

It is possible to operate a private cloud on the physical infrastructure and to provide the virtual infrastructure to the users, who can utilize it to execute their own applications and systems. The infrastruc-ture as a service can open an access to distributed systems to a higher amount of users, who have been so far prevented from using them by a complicated administration, too long process of purchasing and installing computing resources.

The cloud operating on physical servers in different geographical locations can be a suitable complement to the clouds in supercomputing centers.

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