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CONTROLLING MULTIPLE VIRTUAL MACHINES IN COMPUTER CLASSROOMS

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Abstract

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A management of computer classroom is undoubtedly a difficult task for the administrator which has to prepare virtual operating systems for education. It is quite common that lectors need to edit the particular machine during the semester, and that is the case where the main problems can appear. The process of changes deployment is not just very time-consuming but during it a virtual machine inconsistency can appear.

The main part of this paper focuses on system process diagrams and its pseudocode. At first, the machine is created on the remote server by lector or administrator. After a proper approval, the machine is able to be deployed. The lector then specifies the details about date, time and destinations of the virtual machine deployment. Once these details are approved, the virtual machine will be automatically deployed at the specified time. The automatic deployment includes also an initial configuration of the virtual machine at remote desktop and its post-install configuration (hostname, MAC address, etc.). Once all steps are completed, the process will be marked as succeed.

We present an automatized solution which provides a possibility how to easily manage computer classroom with virtual operating systems. The proposed solution should deliver a greater flexibility, more reliability and faster deployment in comparison with the current solution used in our computer classroom. The proposal is also able to manipulate with already deployed machines for easy changes (e.g. software updates). The main advantage is the improvement of classroom management process automation.

Keywords: computer classroom, VirtualBox, workstation management, virtual machine, workstation virtualization, virtualization, student workstations

INTRODUCTION

There are many operating systems available today, therefore colleges and universities try to acquaint students with a number of them. This can be ensured easily with the expansion of virtualization. On the other hand, a virtual machine management system should be employed to cover the administration of the virtual machines. The proposed management system of computer classroom is designed especially for computer network laboratory at the Department of Informatics (Faculty of Business and Economics, Mendel University in Brno) founded in 2009 in order to support courses specialized in computer networking (Pokorný and Zach, 2013). The proposed system can also be used in other university computer classrooms using virtualization without major modifications.

The basic laboratory requirement – multiple operating systems on one student workstation – was recently solved using GRUB[1] boot-loader allowing a multi-boot. The management of multiple

[1] There are several other boot loaders available (e.g. Air-Boot, Boot Camp, LILO)

operating systems on the one workstation was very time consuming, even when operations were trivial, more details about the previous solution was described by Pokorný and Zach (2013). A method of virtual image cloning was used to apply changes on all workstations in the past. We consider these prolonged operations as weak spot of the management of network laboratory at FBE MENDELU.

There are other solutions dealing with the management of desktop operation systems as well. Especially the Virtual Desktop Infrastructure (VDI) is the product providing a remote access to the virtualized desktop operating systems gathered in data center. Another method is using a terminal server (e.g. Remote Desktop Solution – RDS). Both of these approaches need a stable connection to the server which we are not able to provide. The current design of the operating system architecture in our computer laboratory uses one natively installed base system (host system) and a set of virtualized educational operating systems held in particular workstations as virtual images. This solution lets students to work with the base and educational at the same time and moreover, copying of virtual images is more convenient for the classroom administrator than a disk partition cloning. There is the VlizedLab software, a complex system for controlling virtual machines running locally, but unfortunately, this solution does not suit all our requirements.

Our goal is to design a solution which will be able to remotely control multiple virtual machines running locally on multiple workstations with the Windows 8 base operating system. The virtual machines must be virtualized in VirtualBox, because of its advantages for the computer network laboratory (GNU GPL license, CLI management) as was described by Aulehlová, Pokorný and Zach (2012). The aim of this article is to provide a proposal of the system able to facilitate complete management process of the virtual machines including their deployment on all computers in classroom and necessary remote modifications.

MATERIALS AND METHODS

Current State

The current network laboratory contains 17 educational computers. These are running the Windows 8 operating system where the students have only standard user rights with many features locked to prevent the security issues. The host system also has an internet access (depends on teacher's decision). The crucial software equipment of host system is the Oracle VirtualBox where the virtualized operating systems prepared for education are running. There are several types of virtual machines, their platform and software equipment depends on the courses for which they are intended. Detail description of possible virtual machine adjustment is described by Pokorný and Zach (2013).

There are also additional user services as LDAP used for the centralized authentication in couple of operating systems, NFS used for centralized users home folders for more operating systems, FTP employed as centralized data storage space, etc. These are ensured by laboratory server, which is managed via the administrator's computer.

The process of the specific virtual machine creation is very demanding and time consuming process. It currently consists of following steps:

1a. Teacher creates the virtual machine for education directly in classroom. Usually the creation is done at teacher's computer. The main advantage is that the teacher can always be sure that his virtual machine is able to run on target computers (all computers have the same hardware configuration in the classroom). On the other hand, the direct participation of teacher and absence of any communication channel between the teacher and administrator can be considered as disadvantages.

1b. Teacher creates the virtual machine on his own computer and forwards a copy of virtual machine to the administrator after its completion. This solution provides the comfort ambience for the teacher but in comparison with the first case of virtual machine creation (1a), this way provides verification whether the destination computer meets the hardware requirements of created virtual machine. Moreover, more significant problem is how to deploy the created virtual machine to the each destination computer.

2. Once the classroom administrator confirms the virtual machine runs properly, he will take a portable drive and sequentially copy the image file to the all computers. The basic configuration change of VirtualBox has to be made as well.

3. The final part of virtual machine creation consists of modification of the virtual machines one by one. This step is also called the post processing. It originates from our previous experiences, for instance, a hostname change is necessary in virtual machines running Windows and change of network interface names is needed in Unix-based virtual systems.

As noticeable from the previous text, the current process of virtual machines management has a number of drawbacks. The main disadvantage of this solution is the very time-consuming management because the administrator needs to repeat every step on each particular workstation. Furthermore, a discrepancy of VirtualBox settings and post processing can occur across the classroom because there is no solution how to check their proper state remotely.

User Requirements

The user requirements have emerged from the experiences in the FBE MENDELU network laboratory. They are composed from basic needs, and the final proposed model has to fulfill them as much as possible.

1. *Creation and management of the virtual machines* – The virtual machine should be created by administrator and has to meet the basic requirements depending on the machine purpose. A one sample copy of the each virtual machine must be held at a centralized storage prepared for deploying. The configuration files including the configuration of VirtualBox and the post processing guidelines must be the part of the sample copy.
2. *Teacher's adjustment of the virtual machine* – In the next step, the lector chooses the virtual machine that best suits his needs and edits it to the specific educational purposes. This process usually includes an installation of additional software and copying of files that must be available for education. This step has to be done without unnecessary moving of the virtual machine; must be fast and reliable.
3. *System approval with the corresponding security settings* – As described in previous paragraph, the virtual machine is edited by teacher. This possibility can result into the potential security, hardware compatibility and license issues which have to be revealed and fixed before the final deployment.
4. *Reliable and fast deployment including the post processing* – The process of deployment has to be fast as possible. The required changes could appear at once and it is important to prepare the classroom for teaching in limited time. The deployment part must include also the post processing – the setting up the virtual machine on the destination computer.

Used Technology

The currently used technologies were already described. In the final proposed solution we assume the usage of the following technologies:

1. *Virtualization software to run the virtualized operating systems* – We tend to use the Oracle VirtualBox, especially because of its possibility of command-line configuration. This tool also offers wide spectrum of possible settings and exactly fits the needs of our education network laboratory.
2. *Relational database for metadata* – The relational database must provide a place for saving the metadata about offered virtual machines. It must be reliable, scalable and easy to backup.
3. *Storage for the virtual machine images* – The storage of virtual machines has to provide accessibility for more users, possibility to work at same time and separately. These needs are met by the Windows Server 2012, which is the available solution for the university. Another advantage is user-friendly interface for non-Linux users.
4. *Replication software for batch downloads* – A multicast protocol could be deployed for the efficient and fast distribution of virtual image from the server to destination machines. The BitTorrent or the UDPcast suit this purpose best. The differences between these two ways are negligible; however, the BitTorrent is little bit faster as shown by Laurikainen (2012).
5. *Necessary configuration after the image replication* – A direct remote access to Windows workstation using SSH is not possible at fresh install, so additional software (called Cygwin) has to be deployed on these host systems to enable the application of VirtualBox and post processing configuration.

Other Solutions

There are a lot of approaches to manage batch of computers in school classroom. The solution to management can be the terminal approach using the PCoIP, RDP or ICA protocol as Horizon View, Citrix XenDesktop, etc. Also already mentioned solution using machine cloning is a possibility. These solutions are great for common classrooms, but laboratory of computer network or other special cases may require some additional features to be tuned.

The issue of centralized computer classroom management is also discussed in several articles. Only few of them deal with a solution based on desktop virtualization with VMs images stored locally on the workstation. During November 2013 we have searched in main databases (IEEE explore, CiteSeerX, ISI Web of knowledge, Scopus, Google Scholar and Google) using different combinations of keywords (workstation, workstation virtualization, desktop virtualization, virtual machine, workstation management, classroom management, workstation deployment) to provide objective view on current state of computer classroom management based on desktop virtualization.

Jelínek *et al.* (2010) published the system for management of network laboratory, where a web server manages the virtual machines (VM) repository. The system works only on Linux based workstations and the UDPcast is used for distribution of VM to particular workstations. Unfortunately, this system is no longer working.

Jirků (2012) describes the software, which is able to remotely duplicate a VM image and configuration file to the target PC. The access rights on target PCs are changed to prevent VMs settings modification by students. Unfortunately, this solution does not deal with ISO images in terms of central repository as described in our own solution below.

The paper proposed by Wu *et al.* (2010) describes batch remote VM control with an agent service running on workstations. Drawback of the paper is an absence of system for automated VM deployment. One the other hand, the VM distribution process is solved by O'Donnell (2008), where a system using a bitTorrent protocol for VM images distribution over a network is proposed. However O'Donnell

(2008) does not solve a management of these workstations and a central repository.

VlizedLab tool proposed by Matzinger (2013) enables a VM replication from teacher's PC to the selected student computers. It uses a Linux server for machine distribution using UDPcast and offers prepared Linux workstation images, which are easy to configure. This solution does not provide the possibility to use the host operating system as a full computer, but provides the possibility to run more operating systems simultaneously.

Performance of VMs is important as well. Huang *et al.* (2012) deals with performance evaluation of virtualization technologies – VMware, Longene, Wine. The paper written by Shirvaikar and Satyla (2007) provides performance comparison in terms of several criteria, e.g. boot time and file transfer speed.

This paper deals with solution where the VM images are stored locally, but there are also publications, for example Border (2007) or Faměra (2011), which are discussing the solutions based on desktop virtualization on remote server.

As the review of related works shows, none of known solution meets all our requirements for management system for multiple virtual systems in the specialized network laboratory. VlizedLab developed by Matzinger (2013) is the system, which is very close to meet our requirements in comparison with the other solutions. However the drawback of VlizedLab is the impossibility to use a host system for basic work. Despite this, Matzinger (2010), Jelínek *et al.* (2010) and O'Donnell (2008) can inspire us in a way of VM distribution. As well Jirků (2010) and Wu *et al.* (2010) can contribute with the solution to remote control.

RESULTS AND DISCUSSION

Used Terminology

Following terminology is used in this chapter:

- *Virtual Machine (VM)* – a virtualized computer system running inside a virtualized engine (e.g. VirtualBox) on a host system which is installed on a workstation.
- *VM Template (VMT)* – a prototype of VM with a basic set of software equipment and initial settings. The template VM can be used as a sample for a new specific adjustable VM which is intended to be deployed on workstations.
- *VM Repository (VMR)* – a database of all VMs, either VMTs, VM proposals or deployed VMs.
- *Deployment Task (DT)* – a scenario stipulating which VM is to be deployed on which workstations in a scheduled time.

System Design

The main system processes in the virtual classroom management model have two entities (roles) interacting with the system – an administrator and a teacher. The teacher (as a user) prepares a specific VM according to course needs (by means of the VM Repository Management process), and issues a DT request (using the Deployment Task Management process). The administrator holds responsibility for the whole system and performs specific management tasks, e.g. preparation of a VMT in the VMR and approval of a modified VM as well as approval of a DT request. The Workstation Management process represents the actual deployment of VMs onto course workstations, post-installation processing, and it provides both of the entities with a result of the VM deployment.

Description of Subprocesses

VM Repository Management Process

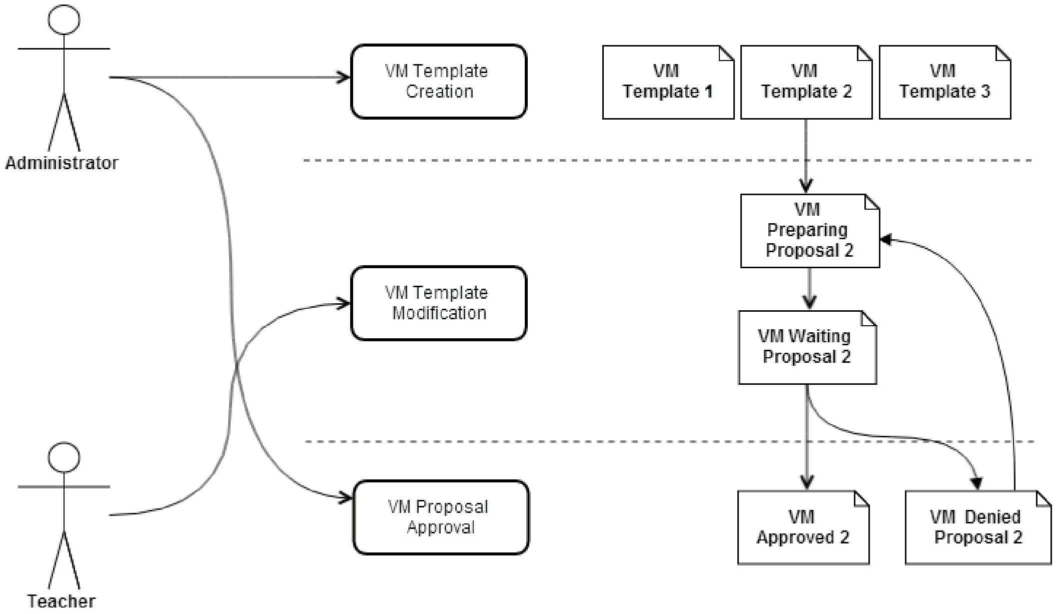
VM Repository Management Process (scheme in Fig. 1) can be decomposed into three subprocesses – VM Template Creation, VM Template Modification and VM Proposal Approval.

The key term in the VMR is the VM, which can get into several VM states:

1. VM Template (VMT) – a new sample VM as described in the terminology section above.
2. VM Preparing Proposal (VM PP) – a modified VMT, typically with new software added by the teacher, but not finished yet.
3. VM Waiting Proposal (VM WP) – a modified VMT, which is finished and waiting to be approved by administrator.
4. VM Approved (VMA) – a verified VM (previously in the state VM WP), which was checked by the administrator for VM's consistency and was approved for deployment.
5. VM Denied Proposal (VM DP) – VM WP was checked by the administrator for VM's consistency and was not approved for deployment. Teacher has to modify it (get it into VM PP state) or delete it.

The VM Template Creation process is used by an administrator to create new VMT. The administrator can prepare VM locally and then import it into the system. Other option is to create a VM on the server with setting all HW properties, installing OS and all necessary software. In both cases it is important to set a network card mode (bridge or NAT) and related security settings (firewall, antivirus, update policy, administrator rights for students, etc.) according to station purposes. For post-install configuration, it is also useful to add management interface, which has connection only with host workstation. When all these conditions are met, the new VMT created. The pseudocode of VM Template Creation process is as follows:

```
IF import existing VM
  THEN
    upload and register in the system
  ELSE
    create new VM
```



1: *Decomposition of VM repository management subprocess*

```
    set HW requirements - CPU, RAM, HDD,
    CD-ROM, USB, INET MODE,…
    install OS and SW
    IF VM OS/Software needs license
      THEN
        add appropriate licence for OS
    END
    add management interface
    IF VM has access to Internet
      THEN
        set NAT mode
        install security SW
        perform security settings
        create non-root account
      ELSE
        set BRIDGE mode
        set network card MAC and
        interface name
    END
    check VM functionality and security
    (antivirus, FW, admin rights)
  END
write a comment for terms of usage
mark VM as VM Template (VMT)
```

Teacher can choose any VMT or VMA as a template for his/her own VM and possibly install additional application software according to course needs. This process follows the VM Template Modification process shown in pseudocode:

```
choose VM to modification (VMT, VMA, VM
DP)
mark VM as Preparing Proposal (VM PP)
WHILE VM is NOT finished
  DO
    make desired changes (increase HW
    requirements, install own SW)
    check added software license
    usability
  DONE
write changes into comment
mark VM as Waiting Proposal (VM WP)
```

Until the VM is finished, it is marked as VM PP. Once the teacher finishes the VM modification, he/she designates the VM as a VM WP. After that, the VM WP enters into VM Proposal Approval process, where the administrator checks/ensures the VM's consistency and if the VM meets all the deployment requirements, it gets an approval status (VMA). The VMA is now ready to be delivered onto the end workstations. Otherwise the VM WP is rejected and marked as VM DP. Then the teacher has to fix the VM DP according to the administrator's notes and then issue a new VM Proposal Approval process. The pseudocode of VM Proposal Approval process is as follows:

```
choose VM WP to approve
IF HW requirements AND security settings
AND installed SW licenses ARE acceptable
  THEN
    change VM state to Approved (VMA)
  ELSE
    write a comment
    set VM state to Denied Proposal (not
    accepted)
END
```

Summary of the VM's consistency and VM deployment requirements:

- VM hardware resource allocation (CPU, RAM, HDD) according to OS and software needs.
- Specific VM settings (network mode: NAT by default, Bridge as a special case is possible).

- Security software and settings (firewall, update policy, antivirus) in case of Internet access.
- Valid software licenses for operating system and applications.
- User logon policy (local admin privileges, local non-admin, Active Directory or LDAP).

Deployment Task Management

Deployment Task Management in Fig. 2 is composed of two subprocesses – first is the Deployment Task Specification process, where the teacher or the administrator specifies which VMAs are to be deployed to which classroom (workstations) and when. This will create a Deployment Task (DT) which has a Proposal state because it has to be approved by the administrator. The pseudocode of Deployment Task Specification process is described bellow:

```
choose VM for DT specification
IF VM state is VM Approved (VMA)
  THEN
    choose destination classroom
    (workstations)
    choose date and time of deployment
    create new DT with state Proposal
    (DTP)
END
```

The DT Proposal enters into the Deployment Task Approval process, which is in the following pseudocode:

```
choose DT Proposal (DTP) to approve
IF DT requirements meet workstations
hardware capabilities
  THEN
    set DT state to Approved
    IF exception
      THEN
        write a comment
    END
  ELSE
    set DT state to Rejected
    write a comment
END
```

The administrator verifies if hardware requirements of the VMA meet hardware capabilities of workstations in the classroom. This can be done automatically as well but a database of hardware equipment (incl. storage space that is currently used on the workstations) would be necessary in this case. If the intended target workstations cannot run the VMA the administrator rejects the DT Proposal. Then the teacher can issue a new DT Proposal, which will follow administrator's notes (e.g. specify a different classroom with more powerful workstations). If the DT Proposal is correct, the administrator will set the state to DT Approved.

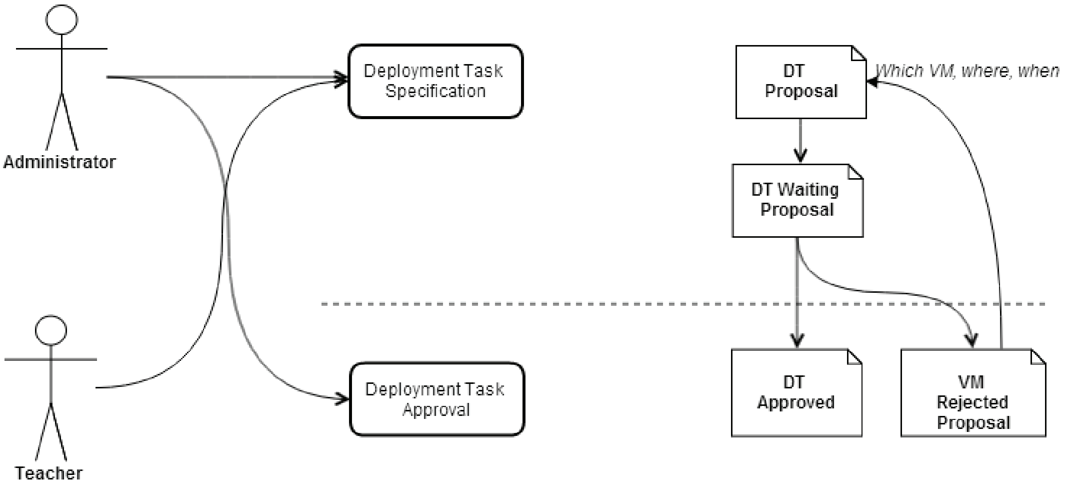
Workstation Management

The Workstation management process is described in Fig. 3 which comprises all subprocesses needed for successful VM deployment on real workstations.

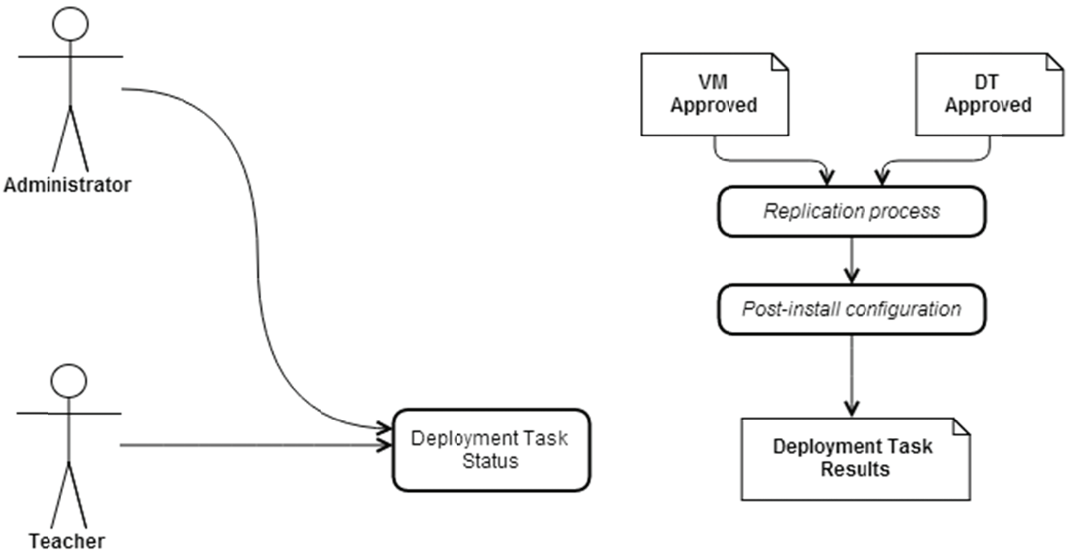
At first the *Replication process* receives two key inputs – the VM Approved (VMA) and the DT Approved (DTA) with the instructions how to deploy the new VM. The Replication process performs these steps:

1. The VMA is copied from the VM repository (VMR) to all workstations in selected classroom (according to DTA).
2. These VM files are verified (e.g. with a hash function) to ensure that the file transfer was correct.
3. A new VM is registered in the virtualized environment at each workstation.

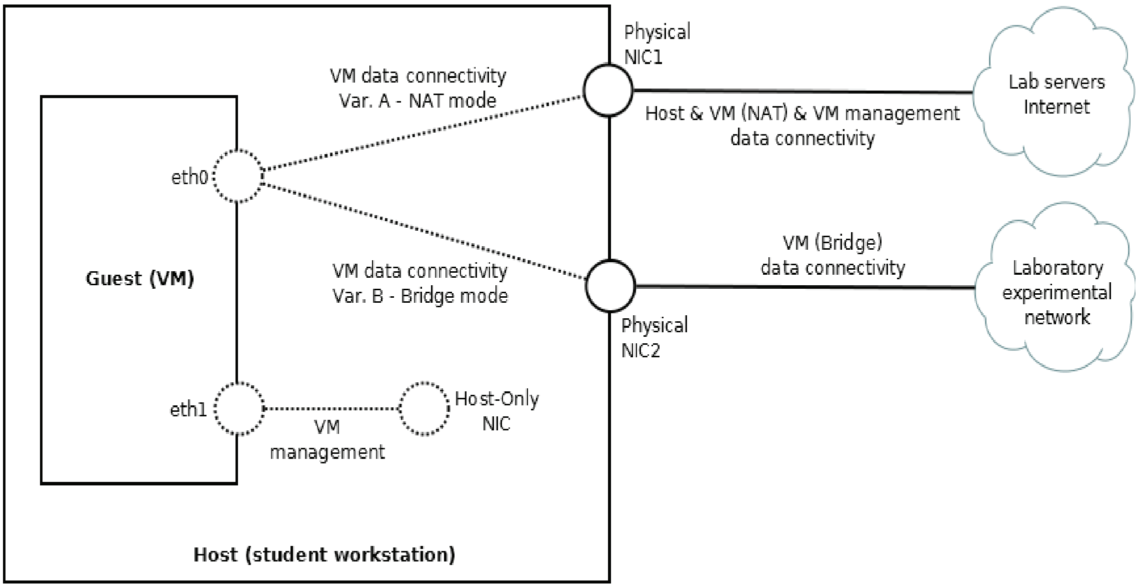
Before the new VM can be used by end users, a specific post-installation settings has to be performed. In the first step of the *Post-install configuration process* the internal (management) network interface need to be set in the VM. It



2: *Decomposition of Deployment Task Management subprocess*



3: *Decomposition of the Workstation Management subprocess*


Physical NIC1
VM data connectivity Var. A - NAT mode
Host & VM (NAT) & VM management data connectivity
Lab servers Internet
eth0
Guest (VM)
VM data connectivity Var. B - Bridge mode
VM (Bridge) data connectivity
Laboratory experimental network
Physical NIC2
eth1
VM management
Host-Only NIC
Host (student workstation)

4: *Connection between Guest VM and host workstation via the Internal NIC (Host-Only NIC) for management purposes*

is used to perform specific remote post-install configuration.

In Fig. 4 there is an example of possible situation after image upload to a workstation. A connection to the host operating system is accomplished through the interface NIC1, after that the guest system can be booted up using VirtualBox's command line. Then it is possible to use the internal network interface card for connection into the guest system and accomplish post-install configuration.

In the VM configuration a primary network card mode has to be chosen. The most usual is the NAT mode with no additional VM settings needed. This mode suits requirements for VMs that require internet access, students don't have administrator privileges in this mode. But in special cases (e.g. network laboratory), it is necessary for the students to have administrator privileges to be able to modify the VM's network interface card IP settings, and to expose the VM to an experimental educational network. Then the network card mode is the Bridge mode, and a few configuration adjustments are needed:

- The VM's MAC address has to be unique (usually set in the virtualized engine environment).
- The VM's unique IP configuration and hostname may be necessary (set inside the VM).
- Other VM's OS specific settings may be needed (e.g. Linux interface mapping, ethX).
- Also the VM's virtual disk should be mounted as immutable to return all VM changes made by students to the VM's initial consistent state.

Both the teacher and the administrator need to know the result of the deployment task. Using the Deployment Task Status process (as described in pseudocode below) the administrator finds out whether the replication and post-install configuration sub-processes reached their final positive states – then the administrator closes the case as a successful one and the teacher is ready to start teaching his/her course. In case of problems the administrator needs to reveal the cause of the problem and try to solve it manually, or to start the whole deployment process from scratch. The pseudocode of Deployment Task Status process is shown bellow:

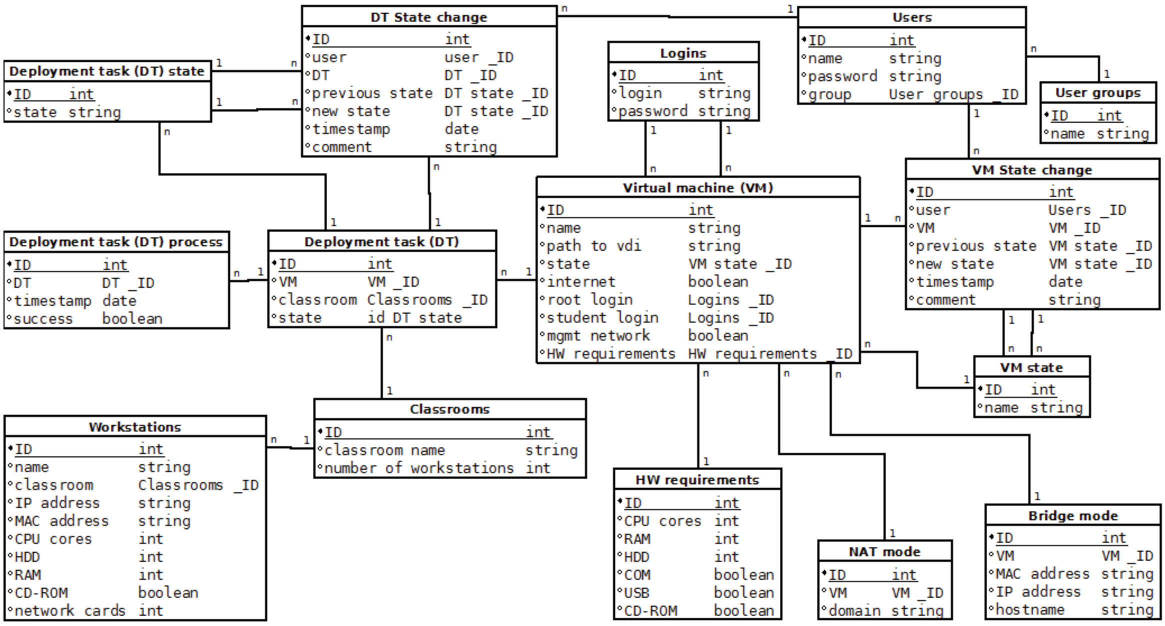
```
Choose DT Result
IF DT result IS failed
  THEN
    IF reason of failure IS problem in
    replication process
      THEN
        repeat image upload to this
        workstations
    END
    IF reason of failure IS problem in
    Post-install configuration
      THEN
        repeat configuration on this
        workstations
    END
END
```

The Entity Relationship Model of the Management System

The entity relationship model was created using a knowledge acquired in creating function processes of the whole system. It includes a possibility to deploy the management system to more classrooms as well.

In the center of the entity relationship diagram (Fig. 5) there is the VM which keeps all information about VMs described in the VM repository management. This includes VMs' hardware requirements (stored in the HW requirements table) and network card properties (stored in the NAT/Bridge mode table). The table Logins keeps information about login accounts to a particular VM's operating system. The VM State change table tracks changes during the repository management process, the VM state table contains all the individual VM states.

Main table for the VM deployment is the Deployment task (DT) table which is followed by the Classrooms and the Workstations tables. The Deployment task (DT) state table contains possible DT states, and the DT State change table tracks every state change during the deployment confirmation (by admin) and its application on real workstations. The tables Users and User groups store all registered users in the system. The Deployment task (DT) process table is used for the final state of the deployment task assignment.



5: *Entity relationship diagram*

CONCLUSION

In this paper we presented one possible approach how to disseminate and manage multiple virtual workstations in computer classrooms. Other solutions how to deal with this problem were mentioned in the paper, however, none of them is completely suitable for our needs. We presented user requirements based on the environment at the Department of Informatics at FBE MENDELU in Brno, and described key ideas of the design of a new system that we are going to implement in the near future. The design contains mainly description of system processes in graphical form, all the main processes are described with a pseudocode as well. In the end, the design is completed with description of the data model using the ERD diagram. After implementing the system, we would like to expand this system beyond our network laboratory and deploy the system in a larger scale at our university.

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