



## LABORATORIES FOR TEACHING OF MATHEMATICAL SUBJECTS

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**Abstract:** We have adapted our two laboratories at our department based on our research results, which were presented at the conference CADGME 2014 in Halle and published in the journal [1]. In this article we describe the hardware and software structure of the Laboratory 1: LabIT4KT-1 -- Laboratory of Computer Modelling and the Laboratory 2: LabIT4KT-2 -- Laboratory of Numerical Mathematics. We explain the functionality of these laboratories in teaching mathematics courses at our faculty with priority given to usage of freely available software. We describe why we have made some changes in the laboratories and how these changes assist in their operation. We focus mainly to teach the following mathematical subjects at these laboratories: Operational Analysis, Linear and Quadratic Programming, Numerical Mathematics, Applied Statistics, Queuing Theory, Software Computing Resources, Software tools for modeling processes, Applications of Differential Equations, Optimization Methods, and Fundamentals of the TeX, (LaTeX).

**Key words:** Teaching, Mathematical Software, Mathematical Subjects, Laboratories

### 1. Introduction

In article [1] I have explained how to use software for teaching mathematical subjects at Department of Mathematics and Informatics of Faculty of Electrical Engineering and Informatics and also Department of Aerodynamics and Simulations, Faculty of Aeronautics, Technical University in Košice. Usage of some applications in various subjects and using easily accessible software we can see in [11, 12, 13, 14, 17, 18].

In this article I will not describe how to use this software to teach math subjects, but I will describe how we've improved laboratories with mathematical software after experience in teaching mathematical subject in earlier periods. I will describe how we transformed our laboratories so they can be easily installed, used, and modified. The base of this rebuild was scheme of the laboratories that was created under the project IT4KT<sup>1</sup>. During and after remodeling were all functionality for project IT4KT maintained. Also, we use the laboratories for the research project VEGA<sup>2</sup>.

In this article I will make you familiar with our laboratories:

**Laboratory 1:** Laboratory of Computer Modelling (LabIT4KT-1) and

**Laboratory 2:** Laboratory of Numerical Mathematics (LabIT4KT-2).

I will describe the hardware and software structure of these laboratories and the functionality of these laboratories and their maintenance.

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## 2. Software Used in Mathematical Subjects at Technical University

I present software that we used and still are using for teaching mathematical subjects at our faculty, and Faculty of Aeronautics, respectively. I will give the list of subjects in which the software is used.

### 2.1 Installed Software

We established new PC laboratory with limited possibilities at our department in 2006. With the help of several projects, new laboratories were gradually formed with hardware which enables us to use variety of software. Nowadays, four laboratories at DMTI<sup>3</sup> and DAaS<sup>4</sup> are active with relatively modern computers with high speed graphic cards, processors and reasonable amount of memory (RAM).

The software installed on computers (as of 2015, revised in 2017):

- (a) Operating system – CentOS 7,
- (b) LibreOffice (LO Calc),
- (c) WPS Office,
- (d) MATLAB 2016b + toolboxes,
- (e) GNU Octave,
- (f) Maxima (wxMaxima),
- (g) GeoGebra,
- (h) JabRef,
- (i) TeXStudio,
- (j) LaTeX -- TeX Live.

In two laboratories we are updating the infrastructure of computers for parallel computations (Parallel Computing Toolbox for MATLAB -- server MDCS) and also usage of graphic cards for mathematical computations and simulations.

In the beginning we had to decide, whether we will use Windows or Linux environment. Even we have started with Windows; gradually we have switched to fully Linux environment. This allowed us to simplify the process of maintenance of multiple classrooms with different types of computers, to remotely control the individual machines, and to connect all computers and use their combined computational power for parallel computations. The choice of Linux also removed threats of virus infections.

The project of Ján Buša available at the website Project KEGA: <http://people.tuke.sk/jan.busa/kega/> Project KEGA - 3/2158/04 - New teaching technologies. -- Usage of OPEN SOURCE software in teachings at universities, deals with usage of open source software at universities (see also [11, 12, 13, 14, 17, and 18]). Therefore we prefer as operating system Linux.

The operating system Windows and software MS Office can be installed on each PC individually using virtual environment (KVM).

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## 2.2 Mathematical Subjects which Use Mathematical Software

At the beginning we used computers only in subjects, such as Numerical Mathematics, Probability, and Mathematical Statistics. Limited number of students could attend these courses due to capacity of PC laboratories. Numerical Mathematics was taught in the second year (third semester) of bachelor study, and now it is in the fourth semester in the bachelor study. Students had already mastered basic knowledge in~programming in C and C++.

We have gradually expanded the use of the software to other mathematical subjects of Bachelor and Master studies at our faculty:

- (1) Numerical Mathematics, Probability, and Mathematical Statistics,
- (2) Operational Analysis,
- (3) Linear and Quadratic Programming,
- (4) Numerical Mathematics,
- (5) Applied Statistics,
- (6) Queuing Theory,
- (7) Applications of Differential Equations,
- (8) Optimization Methods,
- (9) Fundamentals of Typography (TeX, LaTeX).

We also use PC software in these subjects at Faculty of Aeronautics:

- (1) Applied Mathematics,
- (2) Numerical Mathematics,
- (3) Selected Chapters from Mathematics<sup>5</sup>.

At Faculty of Aeronautics the lectures and exercises of PC started at request of technical departments. Departments requested to use programs MATLAB and MS Excel for calculations.

We have created two special subjects at our department that facilitate the use of mathematical software in the above mentioned mathematical subjects since 2015:

- (1) Software Computing Resources,
- (2) Software Tools for Processes Modelling.

The first of them is taught at bachelor level of study and the second at the Master degree of study.

## 3. Laboratories

In this chapter I will describe the gradual evolution and building of laboratories for our department. I will describe the problems that need to be resolved. I will present innovations and enhancements that simplify the use of existing laboratories.

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<sup>5</sup> Selected Chapters from Mathematics is subject for PhD students. These subjects cover numerical mathematics, probability, mathematical statistics, and mathematical optimization.

### 3.1 The Previous State of Laboratory

At the beginning (2006) we had only one numerical mathematics lab with twenty computers. It were a computers with weak hardware and CRT monitors, which covered a lot of desktop space. The software was installed for an individual on each PC from CDs (Windows XP, MS Office and MATLAB 2007). Such configuration caused many problems by computer maintenance and as well as by use of students.

The most frequent problems:

- (1) Long time of software installation. Complete preparations of the whole laboratory at the beginning of the semester have required at least a week. On each PC was installed Windows XP from a CD, then update the operating system was done via internet. After successful installation of Windows XP was installed MS Office. After its installation, it was necessary to repeat the updates via internet. The last was installed MATLAB 2007 with license validation maintained by the university license server. In the case that any installation failed, the process extended for more than one week.
- (2) Changes to the desktop of PC. Students often had different desktops on computer during the semester. Most often it was caused by other students on previous laboratory sessions when they changed desktop background, changed the location of icons on the desktop, or deleted them, or added them. Such changes on the desktop of PC, caused delays in the exercises, because the students had problems to run required programs.
- (3) Files access. Students often saved files in computer. These files were not available, if students were sitting at another PC during other exercises.
- (4) Missing choice of operating systems. Students complained that they have not the opportunity to work in a Linux based system. They asked, why is only available operating system was Windows XP.
- (5) Cleanliness of system. Before the exams teachers had to check each PC for that will give remove hidden files from students (as an illegal aids in the exam test). Such control lasted sometimes for hours, if controls were performed by single teacher.
- (6) Limited workspace. CRT monitors covered a large part of the table on which they were placed. The students had little space for taking notes.

This solution of laboratory was very inflexible and very time consuming to maintain. Also students felt discomfort when using the PCs installed in such laboratory.

The laboratory of numerical mathematics has been equipped with new HP computers with LCD monitors and 24 ports switch with 1 GB line into university network about a year and a half later. At that time my colleague Ján Buša jr. and I decided to modify numerical mathematics laboratory so that we can eliminate as many as possible problems we identified in the previous period.

The changes we have conducted:

- (1) We have canceled installation of individual computers. We installed a sample computer with all the software that we wanted to have. Then we created a computer disk image and saved it at the faculty server of the computer center. From this PC centre a PC disk image was loaded onto any PC in the laboratory. Thus we were able to almost simultaneously install a disk image on all twenty computers. After having image created, installation of all 20 computers simultaneously took less than 70 minutes. Thus was shortened preparation time of laboratory for the beginning of the semester to a maximum of three days.
- (2) We've added to PC Windows XP even Linux. At start up of PC, students could choose in a simple menu in which OS they want to work (Windows or Linux). Then selected operating system was loaded and students had available standard software for both OSes.

- (3) We have installed MATLAB 2007, MS Office. We added GNU Octave, Maxima and LibreOffice. MS Office was not installed in Linux. Added software responded to the demands of students and our experience we have obtained and is described in article [1].
- (4) In Windows XP, we limited change of desktop background of PCs by the students and adding and deleting of the icons on the desktop.

Even despite these changes, we were unable to remove all the problems in numerical mathematics laboratory.

- (1) Installation time remained too long despite the fact that the laboratory was connected to 1GB internal university network and installation of computers went almost parallel. It required about 2-3 hours and then fine-tunes the software (for OS Windows and OS Linux) and installs updates for Windows and MS Office. This extended the installation to 1-3 days.
- (2) Inflexibility when you install the latest version of software, or their updates. Make changes in the sample image meant to perform a sample installation of PC, which was time consuming.
- (3) Files that students created and uploaded to the PC during exercises remained in the computers and were accessible to other students during the semester until they were cleared. This required the teacher to check before each exam in each computer of the laboratory for unwanted files and remove them. This action was again time consuming.

All these facts and experience were the basis in order to innovate existing laboratory and to ensure the teaching of mathematical subjects according to the experience described in the article [1], so that we have reduced the time needed for maintenance of laboratory and eliminate as many problems which we have identified in previous versions of numerical mathematics laboratory.

### 3.2 The Current State of Laboratories

Laboratories in our department are placed in four rooms. Three of them are designed for teaching of the students and fourth room is a server room in which are installed servers, necessary for the proper work of our laboratories.

#### (1) Laboratory of Computer Modelling:

The laboratory consists of two rooms, and server room:

**Room 1:** 12 PCs, projector, 3 switches, router, 3 web-cams, interactive whiteboard

**Room 2:** 4 PCs and 1 main PC, projector,

#### (2) Laboratory of Numerical Mathematics:

The laboratory consists of one room, and server room:

**Room 3:** 20 PCs, projector, 1 switch, 3 web-cams, interactive whiteboard

#### (3) Server room:

3 servers, air-conditioning, UPS (this room is common to both laboratories).

### 3.3 Laboratory of Computer Modelling

In this part I will describe the hardware and software in the individual rooms of laboratories and the subjects taught there.

#### Room 1:

##### Hardware:

**Personal computer:** Intel Core i7, 4GB RAM, 1TB HDD, **web-cameras**, **switches:** Cisco, 24 ports, **router:** Cisco, **data-projector**, **multimedia whiteboard**, and **electric projection screen**.

**Software:**

Operating system -- CentOS 7, MATLAB 2016b, Statistics Toolbox, Optimization Toolbox, Parallel Computing Toolbox, Symbolic Math Toolbox, Partial Differential Equation Toolbox, Maxima (wxMaxima), GNU Octave, LibreOffice, WPS Office, LaTeX -- TeX Live, TeX Studio, JabRef, GeoGebra.

**Subjects:**

Laboratory designated for regular teaching schedule -- Operational Analysis (Linear optimization), Linear and Quadratic Programming, Applied Statistics, Fundamentals of Typography (TeX, LaTeX), Applications of Differential Equations, Queuing Theory, and Software Computing Tools.

**Room 2:****Hardware:**

**Personal computer:** Intel Core i7, 12GB RAM, 1TB HDD, graphics card NVIDIA GTX 660, **dataprojector**, and **electric projection screen**.

**Software:**

Operating system -- Windows 7 -- 64 bit (CentOS 7), MATLAB 2016b and toolboxes, GNU Octave, Maxima (wxMaxima), LibreOffice, WPS Office, MS Office, LaTeX -- TeX Live, TeX Studio, JabRef, software for programming in MS Windows (Delphi), C++, and software for creating and testing applications on graphics cards, special software for visually impaired students (only main PC).

**Subjects:**

Laboratory designated for individual lessons -- Software Tools for Process Modelling, LaTeX, Computer Modelling, Modelling of Physical Processes, Optimization Methods, and students' theses.

**3.4 Laboratory of Numerical Mathematics****Hardware:**

**Personal computer:** Intel Pentium Dual Core, 2GB RAM, 160GB HDD, **web-cameras**, **switches:** Cisco, 48 ports, **projector**, **multimedia whiteboard**, and **electric projection screen**.

**Software:**

Operating system -- CentOS 7, MATLAB 2013b, Statistics Toolbox, Optimization Toolbox, Parallel Computing Toolbox, Symbolic Math Toolbox, Partial Differential Equation Toolbox, Maxima (wxMaxima), GNU Octave, LibreOffice, WPS Office, LaTeX -- TeX Live, TeX Studio, JabRef, GeoGebra.

**Subjects:**

Laboratory designated for regular teaching schedule -- Numerical Mathematics, Operational Analysis, Linear and Quadratic Programming, Applied Statistics, Queuing Theory, Fundamentals of Typography (TeX, LaTeX).

**3.5 Server Room**

In this part I will describe the hardware and software of the server room.

**Server 1 -- Cisco:****Hardware:**

2x Xeon E5-2640v2, 16GB RAM, 3x300GB SAS HDD (2x300GB RAID1, and 300GB scratch).

**Software:**

Operating system -- CentOS 7, VirtualBox, KVM, software for web-cameras.

**Provides:**

- (1) IPA -- Identity Policy Audit (KVM),
- (2) Virtual test machine (KVM),
- (3) Common desktop,
- (4) Installation files -- kickstart.

**Server 2 -- Mathworks HeavyHorse:**

**Hardware:**

2x Opteron 4386, 32GB RAM, 10.25TB HDD (2x4TB RAID1, and 2.25GB scratch).

**Software:**

Operating system -- CentOS 7, MATLAB Distributed Computing Server, VirtualBox, KVM.

**Provides:**

- (1) MATLAB Distributed Computing Server,
- (2) Parallel Computing Toolbox (MATLAB),
- (3) SAGE -- (in preparation).

**Server 3 -- HP ProLiant:**

**Hardware:** 1x Xeon E3-1220v2, 4GB RAM, 10TB HDD (2x5TB RAID1).

**Software:** Operating system -- CentOS 7.

**Provides:**

- (1) Archives data from IP cameras,
- (2) Data archiving for system IPA,
- (3) BackUp of installation files,
- (4) BackUp of servers.

### 3.6 Diagram and Functionality of Laboratories

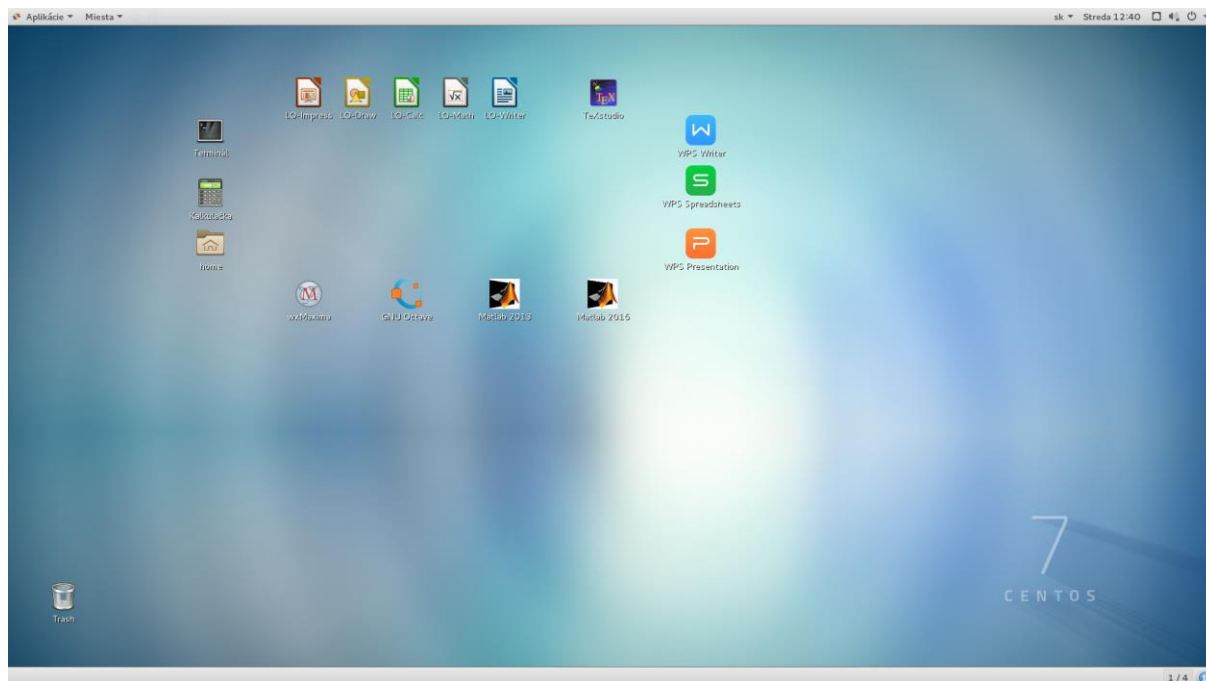
The whole system in the laboratories is designed so that all computers in the labs can be reinstalled in the short time so that students at each exercise have the same operating system, software, and desktop in which they will work.

Kickstart text file is used for swift and consistent installation of all PC's in the labs. This file is located on the Server 1. Kickstart contains all the instructions needed to install the operating system CentOS 7 and all software that is used on the PCs, and rules to ensure uniform desktops on all computers, and all exercises throughout the whole semester. The software is updated automatically after each reinstall, except MATLAB.

Home directory of user student is removed at system startup and is replaced by unified home directory for user student. Whenever one turns on the PC every student has the same desktop and home directory.

If somebody needs to modify your desktop or home directory, he needs just to edit the configuration file saved on the Server 1 and after the restart of the PC the system will load new workspace and home directory.

In this way, we can place files necessary for concrete exercise on all desktops, and students can use them during the exercises. An example of this unified desktop is on Figures: Figure 1 and Figure 2.



**Figure 1.** Unified desktop in the PC of the laboratory of Computer modelling



**Figure 2.** Detail of unified desktop in the PC of the laboratory of Computer modelling

The Server 1 includes installation of software Cobbler. This software sets the installation server. Cobbler also contains a text file kickstart that contains instructions for installing PC.

The network administrator of the university controls the assignment of IP addresses through centralized DHCP services and DNS servers. Administrator of the network allows certain IP addresses on our network (for example the computers in our lab) to be redirected (routed) to a Server 1 on program Cobbler. The Cobbler starts boot-enabled PC menu where you can choose the installation of

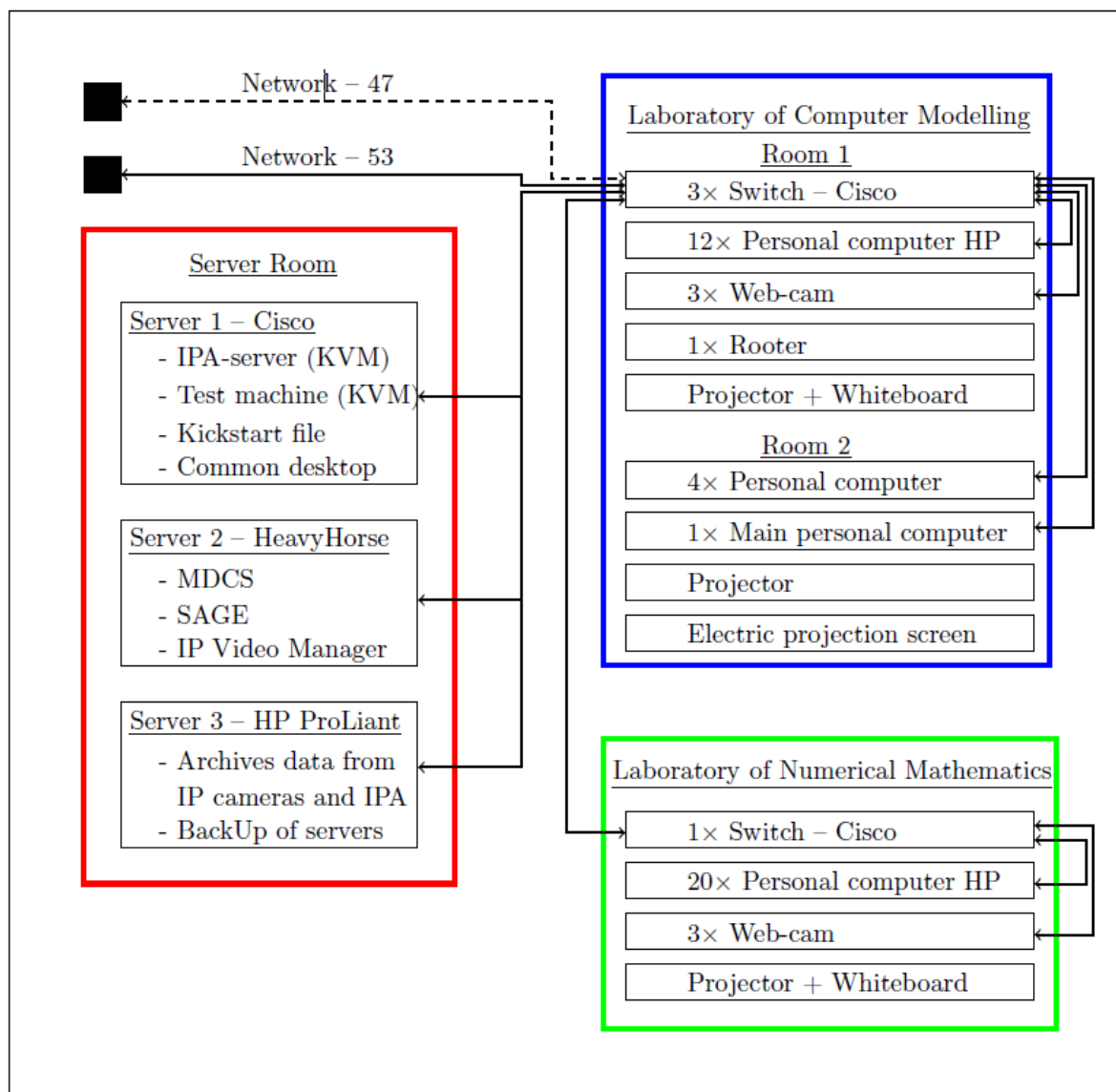


PC from stored file kickstart. Otherwise the PC will boot from the hard drive where the operating system is installed. Server 1 includes installation of virtual machine (KVM) on which is installed and configured software IPA server, Free IPA, kerberos, and LDAP. The kerberos software verifies passwords. LDAP contains a database of users and information about them. Free IPA program simplifies usage and work with kerberos and LDAP. Free IPA has a web interface.

With this technology it is possible to assign access rights, restrictions, and control work on individual PCs. An exception is the restriction of internet access, which is managed by administrator of university network, because we were not allowed to use our own router inside of the university network.

Server 2 includes the installation of a virtual machine (KVM) on which is installed and configured software of camera system in the laboratory. With this software we can watch on-line footage from the cameras through the university network and automatically back up for security reasons 14-day records of these cameras to the Server 3.

Schematic diagram of the whole structure of laboratories one can see in the Figure 3.



**Figure 3.** The Scheme of the Laboratories at DMTI

Reinstallation of the Laboratory of Computer Modelling takes approximately 30 minutes. Reinstallation of the Laboratory of Numerical Mathematics takes approximately 70 minutes, since there are power weaker machines.

When installing computer, the system recognizes in which room the installation of computer is carried out and chooses the appropriate configuration (for example in the Laboratory of Numerical Mathematics instead MATLAB 2016b it installs version MATLAB 2013a, in order to cope with the weaker machine).

These values are very favorable to the administration and maintenance of software in the labs. Before, when we need manually installed PCs of the Laboratory of Numerical Mathematics for Windows XP, it took about two full working days and we could not control the stability of the user's environment.

I describe the benefits of each innovation and I explain how these changes have contributed to improving the maintenance of the laboratories and more comfortable usage these labs by the students:

- (1) Significant time savings. Due to choice of operating system Linux and using the installation file kickstart for install computers in laboratories reducing significantly the installation time of computers in described labs.

Another operating system is installed only in a virtual machine (Windows 7, Windows 8, Windows 10, etc.). Even with all updates and software. If necessary, we create a copy of virtual machines and they are archived and we do not have to re-install them. These virtual machines are simply added to the installation file kickstart. All computers are installed in the laboratory in 30, 70 minutes, respectively with no need for further interventions and updates.

- (2) Centos7 operating system. Why I chose this operating system. I prefer Linux operating system before OS Windows, because the installation of whole PC will take place in less time and there is no need for any further installation and download of updates for the OS and MS Office. I chose OS Centos7 for its stability and it no need for many and frequent updates. In these laboratories we do not create software, but we use the existing mathematical software, and it is why I prefer stability before absolutely latest versions of the OS. This operating system did not cause any conflicts with hardware that is on our computers and even in servers.
- (3) The same structure of the desktops. Student has available on each seminar the same structure of the desktop in the described laboratories when student turn on computer and start the OS. This change was even appreciated by students and colleagues from the department who teach in these laboratories.
- (4) Storing files on computer. On each computer in the lab are two universal default accounts. One is administrator's account and the other is for students. Students can save files under that anonymous account (student) throughout its work on the computer until the PC is not turned off. If the computer is turned off and then turned on again, the computer again loads the default desktop and empties directories of the student account, i.e. all files stored under this account are deleted. This functionality ensures that before the exam teachers need not to check all computers to see if there accidentally students left some files. This is another time saved for teacher and administrator of laboratories.
- (5) Storing files on server. Students can save files to the server (Heavy Horse) if they want to use them for other exercises during the semester. This enables IPA server to assign an account that they can log on any computer in the laboratories of the department. The administrator can limit student access to the PC with respect to the room where the computer is located, it may be determined exact PC to which the student has to log, respectively. Also it may limit the size of storage space.
- (6) Promote teamwork. IPA server assigns the Student Account. Student can by this account also join the application GitLab. It enables communication, administration, and management of the joint project of students or students with the support of the teacher.

Teacher has an overview of the status of projects and students are not restricted only to working in a laboratory.

### 3. Conclusion

We created PC laboratories with numerous installed programs for teaching subjects at Department of Mathematics and Informatics of FEEI TUKE. The students are able to decide which software they use for solving math problems. This type of software should improve the students results but only if they are familiar with it and are able to use it effectively. For this purpose two new subjects were introduced: Software Computing Resources and Software Tools for Processes Modeling. Students have the same computing environment for all exercises throughout the whole semester with a minimum of effort for the maintenance of all machines.

This system allows teachers to centrally prepare and distribute educational tasks to the computers in the selected lab, or to the selected computers.

In the future we would like to expand the available software and introduce new high speed servers and computers. We would like to prepare new studying concepts which will partially include software usage in teaching some of the subjects. At the same time we are preparing the project about students experience and opinions with software usage in solving some of the problems (electronic checklists).

We applied GeoGebra program for linear and integer programming in the subjects of Operational Analysis and Linear and Quadratic Programming. We are planning to publish the results of this change in the future. Currently, we use for example the literature [2, 3, 4, 5, 6, 7, 9, 10] that we plan to modify, so that an even greater number of subjects can be supported by our mathematical software.

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