BWLEHRPOOL - A JOINTLY MANAGED AND FINANCED INTER-UNIVERSITY IT PROJECT

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Abstract

bwLehrpool is a software suite and IT project grown out of a local initiative of the professorship in communication systems associated with the computer center of the University of Freiburg. It currently manifests an almost sustainable state-wide service offered for higher education and research institutions with aspirations of attracting a wider user base beyond the boundaries of Baden-Württemberg. It fills a niche for efficient management of large computer pool installations with flexible requirements without forcing out existing installations and concepts. Additionally, it responds to new requirements such as orchestrated reconfiguration of pools for larger e-assessments or system automation and monitoring. The project is a combination of existing software stacks including standard Linux distributions and hypervisors combined with custom developments which are made available as open-source packages. The programmed tools and services cover a wide range of components from administration and pool configuration web interfaces to software packages used to streamline the stateless LAN booting client setup and manage the various virtualized lecture environments. The system focuses on the fat client concept by creating a flexible Virtual Desktop-like infrastructure offering a broad range of user-created software environments by separating and disentangling the tasks of administrators and lecturers traditionally associated with computer pool management. Development and support are mainly concentrated in Freiburg and Offenburg, but the financially-contributing user base forms a strong steering group and is regularly consulted for the direction of future development, components and concepts.

Keywords: PC pool provisioning, E-Assessment, Virtualized Desktop Infrastructure, iPXE, VDI.

1 INTRODUCTION

Universities and other teaching institutions continue to operate large PC lecture pools which require similar or identical operating system images and software packages. In addition, there are also numerous individual PC-workplaces (e.g., library, learning corner) and special laboratories. The management of such computer pools usually incurs high administrative efforts or operational expenses that can easily surpass the figures for financial expenditures such as hard- and software purchases. A proven strategy to reduce the total cost of ownership is to employ remote boot technologies utilizing pre-existing high bandwidth local networks.

Development started more than two decades ago at the professorship in communication systems at the University of Freiburg, with the goal of creating a highly dynamic PC pool operation and administration project [1], [2]. Traditional software distribution for computer pools based on software packaging is often not suitable or simply too expensive for the highly dynamic requirements at university campuses. Existing software distribution methods are designed from an enterprise perspective but do not honour the peculiarities of research and education characterized by a steady fluctuation of personnel and a wide set of different software environments.

Technically inspired by the Linux Terminal Server Project [3] and similar solutions [4], a LAN booting Virtualized Desktop Infrastructure (VDI) (a different implementation compared to commercial solutions but similar perception from the user’s perspective) was created. In recent years, e-assessments have become much more significant for various faculties raising completely new requirements regarding university resources which are usually not addressed by existing infrastructures. However, pre-existing infrastructures at the various faculties should ideally be re-used. To incentivize switching to bwLehrpool, a non-invasive solution which could co-exist with existing local setups was required. In 2013 and 2015 the Ministry of Science, Research and the Arts Baden-Württemberg (MWK) funded two successive development phases, first for the base infrastructure and then the e-assessment extensions following the vision of a state-wide sustainable service available to all higher education...
teaching institutions [5]. Successfully, additional institutions were won over and joined the service. The growing number of users required the gradual creation of governance structures and a contractual framework. The project had a second, non-functional objective in mind: to offer an open-source alternative to commercial solutions to reduce the number of dependencies and increase bargaining power in an often monopolistic desktop OS market.

2 COMPUTER POOLS FOR TEACHING AND E-ASSESSMENTS

Computer pools are still a relevant resource for teaching a wide range of disciplines in universities. The requirements regarding software packages vary significantly. There are conflicts of interests between the various stakeholders (lecturers, system administrators, students and university or faculty administration). Lecturers demand high flexibility regarding choice of operating system and available applications. If they need additional packages or teaching material to be available or some configuration to be changed, it should not require negotiation with a third party such as a PC pool administrator, but rather be possible through a self-service without having to schedule lengthy rollout tasks. They need a stable and well-functioning teaching environment at the beginning of their course or session at the latest. Lecturers should be supported by the system so that they can focus on their core competencies, the teaching. On the other side, system administrators prefer uninterrupted pool operations, meaning that they would like to avoid repeated adaptation. They usually want to generalize and standardize the course environments for all lectures and to have long cycles between changes. The installed environments should be optimized to minimize risk and to not compromise the central IT infrastructure. They want to see a flexible provisioning of all software resources without additional efforts for example when adding machines or pools. Students would like to pick a computer lab in a location convenient to them and simply have their usual working environment available anywhere. For the departments and university administration, low IT infrastructure and facility costs are the primary concerns. They would like to see the resources efficiently used and their teaching personnel optimally supported.

bwLehrpool creates a flexible base infrastructure by harnessing Intel's PXE remote boot as an alternative to local disk-based startup. By allowing the user to choose from certain configurations during boot-up, a parallel operation of various modes ranging from the regular bwLehrpool Linux system e-assessments to kiosk mode or even local boot can easily coexist. This non-invasive approach allows the re-use of local, existing infrastructures. The administration of hardware (and local installation) is independent of the administration of the remotely booted base Linux. The chosen software environment and configuration within the VDI is absolutely up to the lecturer who builds a custom working environment tailored to the needs of a specific course. The typical preparation time and physical dependencies for installations are avoided as lecturers only deal with virtual machine (VM) images. Additionally, virtualizing the teaching and working environment has the added benefit that every teaching and working environment stays exactly the same, wherever they are used.

Additionally, the bwLehrpool environment supports two variants of e-assessments either using the examination features of established Learning Management Systems (LMS) or providing a fully-featured VM-based desktop environment coupled with an adequate restriction set. LMS-backed tests can be conducted on a browser within a minimal Linux, both restricted to prevent misuse, or within a Windows-based VM running the Safe Exam Browser [6]. The clients can be configured to start in kiosk mode with auto-login as the authentication of the students is done against the LMS, no software additional to a browser is needed. The use of specifically configured VM environments allow additional types of assessments, such as e.g. testing of programming skills, mastering statistics with R Studio or dealing with Geographical Information Systems. VMs with additional software, either from the taught course or for another purpose, are used as the examination base environment while the task description (e.g. examination questions) and results could be handled via a LMS or a special purpose network share. In both LMS-based and VM-based variants, firewall rules can be configured to limit the access to network resources, external devices can be blocked to avert cheating attempts using external storage media. Finally, both the graphical user interface of the base Linux as well as that of the hypervisor are tightly restricted to prevent any attempt to leave the assessment environment.

3 TECHNOLOGY STACK OF THE BWLEHRPOOL FRAMEWORK

Booting over LAN allows instantaneously usable PC clients but requires the efficient provisioning of the root filesystem and individual system configuration. The non-destructive approach of stateless operations is particularly convenient in multi-boot environments featuring different operating systems.
It helps to simplify the root filesystem as it can be offered read-only to a huge number of clients. The configuration and setup procedure has to be efficient because it is repeated at every boot by every client. The implemented hardware auto-configuration including the full GUI setup with graphic adapter specific 3D capabilities and sound in bwLehrpool operations allows for a broad client hardware base of x86_64 capable desktop machines. A growing number of very different machines are covered, so that even special purpose machines for experiments and in laboratories are bootable, lowering administration efforts significantly. Various additional software tools to support specific requirements both for system administration and user interaction were developed.

Traditionally, general purpose file systems like NFS were used for network booting, but read-only Network Block Devices like DNBD3 provide a range of attractive features, which can outperform alternatives across a range of situations. DNBD3 not only allows for caching and proxying at various levels, but also comes with a built-in performance monitor, versioning, and failover functionality. DNBD3 has been developed at the University of Freiburg for the past few years. It is released under a GPLv2 license, and is available as a Linux kernel module for the clients, and a user-space executable for the servers. It is running in production for two highly heterogeneous use cases. First, a distributed setup of campus-wide computer pools with more than 400 connected machines in Freiburg and comparable numbers at other sites in Baden-Württemberg. Aggressive local caching might even allow the use of mobile clients on WLAN infrastructures in stateless Linux operation mode. Second, for large scale research infrastructures for HPC and cloud operations at Freiburg University.

The administrative core of the framework consists of a so-called satellite server which is distributed as a VM container for easy deployment in existing server infrastructures (Fig. 1). The provided web interface offers simple administration: centralized logging from clients regarding potential software or hardware issues like failing hard disks, visualization of utilization of computer pools with a customizable room layout plan, per-pool configuration of reboot or shutdown schedules, forced logout of inactive user sessions, inventorization of hardware, and much more.

### 3.1 Client side software

**vmChooser** is an internally developed QT-based GUI application that presents a list of both Linux and virtualized sessions to the logged-in user. While the Linux desktop sessions are available globally, the list of virtualized working environments can be adjusted for different computer pools. To help users find an environment suitable to their needs, a short description of the VM’s contents, such as information about operating system and installed applications, can be provided by its creator. A typical use case for students and lecturers alike looks as follows:

1. **Login**: Authenticate against the configured, site-specific LDAP/AD/Shibboleth,
2. **vmChooser**: Select the environment to use,
3. **Hypervisor**: Configure and start the selected VM. The created VDI allows a wide range of virtual teaching and working environments.

![Figure 1. High-level distributed bwLehrpool infrastructure view of master and satellite servers.](image)
The only restriction is the support of the installed operating system by one of the hypervisors available on top of the Linux base system. By now, many different environments are in production use by the different project partners including VMs for Java/C/C++ development, Web development, Databases, IT-Security/Penetration Testing, Microcontroller programming (Embedded Systems), Mobile Systems (Android, IOS, Windows Phone), CAD and various e-exams. Currently around 680 different active (used at least once within the last 30 days, as of January 2019) virtual teaching environments exist across the participating universities. Beside that primary use, there is a configurable kiosk mode to boot the machines into e.g. a fullscreen browser with a user-specified URL to be used as research terminals in libraries or as digital signage to display presentations, announcements or the like.

Additional utilities running on the client are: A simple GUI for configuring dual screen or projector setup, with emphasis on automatically trying to do the right thing; a pdf-to-CUPS wrapping printing GUI that will accept generic PDF print jobs from a running VM and relay them to available printers (removing the requirement of updating VMs whenever printers are added or swapped for different models); as well as some scripts for detecting use and monitoring resource usage.

4 EXTENSION MODULES

A simple and intuitive handling of lectures and VM images for the teaching personnel is realized through a Java-based software GUI tool bwLehrpool-suite (Fig. 2) which is available for all relevant desktop operating systems. The bwLehrpool framework allows different ways to create VM-based course material:

- Extending base images to custom needs. The base images are provided by the bwLehrpool-Team (e.g. Windows 10, Linux distributions) or the local computer center (enhanced by university specific configurations or programs)
- Cloning or modifying a user’s existing image (or one shared by a colleague)
- Creating a completely new system image if no template exists (e.g. for exotic Linux distributions or other OSes runnable in one of the provided hypervisors)
- Migrating a VM to and from the cloud (nb., currently a manual process)

The bwLehrpool-suite provides access to all VM images available to the (bwIDM federation [7]) authenticated user (both their own images and all public ones, such as the templates produced and...
updated by the project team). It gives access to the different configuration options such as to activate the visibility of a certain image or limit its availability to certain PC pools only. To create a (temporary) e-assessment environment the tool provides management of network access via blacklist or whitelist and blocking USB devices. Further on, additional network shares beside the user home directory are configurable per lecture environment. To run certain programs at the start of a VM, the bwLehrpool-suite user can provide a custom script that will run inside the VM after bootup.

The Pool Video Switch (PVS) is a further module programmed for the bwLehrpool project. It is a GUI application for the lecturer working in client/server mode on both the PVS steering PC and the individual clients in a PC pool. Usually installed as an additional PC at the lecturer's seat (the bwLehrpool client typically equipped with a projector). It allows streaming display output of a selected client to one or to many other clients in the room. Further features include the lockdown of all or individual machines, which blanks the display and blocks the functionality of keyboard and mouse. It helps as well to allow for better visibility of the lecturer’s screen in suboptimal configurations. The tool replaces hardware solutions which were popular a decade ago but did not keep up with the technological advancement of peripheral connectors. The layout of single PC pools for use in PVS can be configured via an online graphical tool in the satellite server web UI (Fig. 3). The application design focused on being user-friendly and intuitive; it was deliberately kept easy to use to increase acceptance by the lecturers.

![Figure 3. Left: Room planner interface, middle: PVS management console, right: Info panel.](image)

The Boot Selection Service (BSS) allows administrators to configure different modes of operation and time-based control of clients to e.g. schedule the start of an e-assessment environment or to allow a general time control for automatic startup and shutdown of pools for GreenIT reasons. The BSS adds independence of a pre-existing DHCP infrastructure. In PXE-based booting, two components are involved: a DHCP server and a TFTP server with PXE images. Those images initially load a configuration file, based on MAC or UUID, containing boot entries pointing to kernels and initial RAM disk stored on a remote file server. This process is not only static due to the PXE configuration: changing the next-hop address and PXE image names traditionally involves re-configuring the DHCP server. The network uncertainties of UDP file transfers can be mitigated by using TCP powered HTTP for file transfers, supported in newer versions of PXELINUX or iPXE [8]. To overcome the static character of the setup, a new component, the BSS, was introduced. BSS is an internally developed service component which dynamically responds with custom iPXE scripts depending on the attributes of the machine making the request (MAC, UUID) and on the PC pool they are associated with. After the initial handshake with the DHCP server, machines download a generic iPXE image from the next-hop server containing an embedded script automatically chaining to the BSS' web API, including its MAC address and UUID as GET parameters. The BSS then determines its affiliation from these machine-specific attributes and responds with the custom iPXE script to boot that client's operating system from a DNBD3 remote block device.

5 FROM A SOFTWARE PROJECT TOWARDS A SUSTAINABLE STATE-WIDE SERVICE

Cooperation between universities is not only beneficial in terms of financial savings but also as an exchange of knowledge. There are many standard tasks which are more or less the same for any institution with a computer infrastructure, such as authentication or software rollout. There are also several cooperation projects on a study-course level resulting in students that regularly switch working
places within the various campuses of an university and expect to use services or learning environments from their home institution. So instead of creating just another system for only one university, bwLehrpool was designed from the beginning as a state-wide sustainable service. Many cooperation projects do not successfully overcome the hurdle of replacing a depleted grant through alternate sources of finances and/or man power. They often fail when it comes to the point of agreeing upon binding contracts both to deliver and to refinance the service.

The success of bwLehrpool is due to the management and development of the system in close cooperation with the various stakeholders of the participating universities. After the initial development projects (2013-2016), sponsored by the MWK, the state-wide service started with a small group of potential customers with funding for six months’ personnel costs in the first phase. To promote adoption, each potential new partner is granted a rather long free-of-charge testing phase. The bwLehrpool partnership package includes not only access to the service itself but also 2nd level support in case of problems, regular software updates, a ticket system, and comprehensive documentation with tutorials and marketing materials in a centrally hosted wiki. At the moment, there are about 14 universities statewide using bwLehrpool in a productive environment and several others evaluating the system (Fig. 4).

Two-and-a-half full-time employees are necessary for solid operation and further development of the state-wide service bwLehrpool. In cooperation with other state-wide services and universities, a suitable refinancing model was developed which tries to distribute costs equally without overcharging smaller universities. In Baden-Württemberg, each university has to report their student numbers in regular intervals to the State Office of Statistics. The fee for bwLehrpool is based on the number of students of each university. This creates a fair and transparent cost. The transition phase from project to service is co-financed by the MWK for a limited time to compensate the financing gap in the ramp-up phase.

Because of the potential impact some stakeholders are cautious when it comes to changes in their pool infrastructure. However, due to the fact that the system can be easily deployed in one day and the non-invasive approach, universities can try bwLehrpool quickly and at low expense. The evaluation phase is an opportunity to allow potential users to first evaluate the system on a technical
and organizational level before considering upcoming expenses. If the decision is positive, the second half-year period (typically a semester) is charged at fifty percent of the normal rate to allow for a gradual roll-out of the system campus-wide, the third and following period is charged at one hundred percent. The payment is then made annually, cancellation is possible with a cool-down period of two years of commitment to allow for proper planning by the service providers Freiburg and Offenburg.

Cooperation takes place on several levels. In addition to the development and operation of the service, these are the exchange of base VM images and complex teaching environments between different institutions via a central repository. Project governance results from annual meetings of the user group for exchange of experience, information and preparation of strategy and decisions of future development as well as to adapt the financing model. The meetings take place alternately at different universities, which present and demonstrate use cases and hidden potentials of bwLehrpool to start a discussion about possible improvements and features from both a lecturer’s and an administrative perspective. Resulting proposals are summarized and then prioritized by the users and providers together.

For evaluation purposes, usage statistics from consenting institutions were reported centrally. An analysis of the data gathered during the 30 days prior to the last user meeting shows promising numbers:

- 3900 individual client machines of varying hardware configurations
- 680 virtual teaching environments (VMs with various OSes and applications)
- 510 configured and deployed lecture environments
- 78500 individual user sessions
- 12 years of user sessions (longer than 1 minute)

6 CONCLUSION AND OUTLOOK

A successful IT development project depends on several success factors including a sound technical platform, a committed user base, a proper legal framework and sustainable financing with a long-term perspective. It was helpful to start with the objective of a sustainable service in mind. The project sees a growing number of installations and plenty of positive feedback from partners during the regular steering committee meetings. Nevertheless, the refinancing still needs to be pushed to 100+ percent. Thus, an expansion beyond the state of Baden-Württemberg is planned with a partner having background in public sector PC pool projects for schools.

While using Thin Clients and server-based VDI is definitely a viable option, those commercial solutions are rather expensive. bwLehrpool instead builds upon existing fat PC installations which are still the majority in most institutions and are cheaper. The system is highly flexible as the selection of operation mode and environment is possible during the PXE boot as well as after the user login. The broad hardware support enables a wide use of bwLehrpool helping even outside the core application. It continues to increasingly compensate for the less and less available IT personnel for standard administration tasks.

The clear separation of tasks both simplified the everyday workflows for administrators and lecturers and created new possibilities for teaching and learning. The participating universities profit from the exchange of the virtualized working and learning environments. The project promotes the efficient and cooperative use of common infrastructure (PCs and rooms).

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