Examuntu: A Secure and Portable Linux-Distribution for Summative E-Assessments at Universities

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ABSTRACT

As electronic assessments emerged into the academic landscape, specialized software solutions were developed along with them. Nowadays, many e-assessment systems that provide secure environments for digital examinations are available. However, they often lack portability or possess a complex software architecture that is laborious to maintain. In order to address these issues, we developed the *Examuntu* operating system. It provides a robust and secure e-assessment environment, being both lightweight and easily deployable in a wide range of computer pools, while allowing a flexible adaptation to multiple types of e-assessments and their respective software application requirements.

With this paper, our contribution is twofold. First, we present the design of our novel e-assessment environment for computer pools. This includes the basic system architecture as well as individual aspects, such as web traffic filtering, browser security, and configuration management. Second, we report on our use of Examuntu in conjunction with a Moodle LMS during math lectures. Our setup features various question types and an optimized computer algebra system, allowing to parameterize exercises and generate differentiated feedback. We confirm that applied security measures did not negatively impact students by comparing their performance within digital to pen-and-paper examinations. Qualitative evaluations of three different e-assessment types show how students, assessment developers, and exam supervisors benefit from proposed Examuntu environment.

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1 INTRODUCTION

Electronic assessments (e-assessments) have become an integral part of academic teaching. Digital summative assessments introduce new challenges and entail many aspects that need to be considered beforehand [1]. Especially the security precautions that need to be taken by the software environment were found to be a major challenge. Current solutions often lack portability, hence are bound to specific computer labs with their respective hardware. Due to their technical design, extensive work is required in order to deploy them in additional labs. If solutions allow customization, they commonly possess complex system architectures, hereby further limiting ease of portability. Many of these e-assessment environments moreover involve manual configuration overhead for each conducted examination.

Within this work, we present *Examuntu*, a security oriented and portable Linux-distribution we developed to support academic e-assessments in Section 3. It addresses shortcomings of current solutions by combining out-of-the-box security measures with an easily customizable software stack into a lightweight and self-contained exam environment. Centralized roll-out via campus network allows easy portability between computer labs and ensures that every examinee receives an identical software environment. We subsequently report on our use of Examuntu at the Hamburg University of Applied Sciences (HAW Hamburg) in Section 4. Both our teaching-learning scenario and the used software stack are outlined. The performance of the proposed exam environment is assessed by qualitative evaluations, covering three different types of digital assessments we conducted. Besides our primary contributions, an overview of related work is given in Section 2 and a concluding outlook is made in Section 5.

2 RELATED WORK

Among all examined related work, the environment proposed by Ritter et al. [2] is most similar to our contribution. It uses a network booted Linux system to employ basic security measures and web filtering. User applications are further encapsulated in a virtual machine (VM) that is additionally started within the Linux system. A similar architecture is used by the Alpen-Adria-Universität Klagenfurt [3], though only providing one fixed Windows VM, in which a Safe Exam Browser[1] (SEB) instance is run. Replacing the minimalistic Linux system with a virtual desktop client, executed in a secured SEB context, is done by Schneider et al. [4]. Each virtual desktop then again runs another instance of the SEB, which is used to interact with a Moodle learning management system (LMS). All the above solutions encapsulate multiple operating systems (OSs). This results in complex software hierarchies and negatively impacts system performance. As these solutions are not designed to be lightweight and portable, they entail an extensive amount of work for deployment and configuration. Easy transfer between computer labs therefore is hard to achieve, hereby limiting the flexibility of examinations.

Besides OS-based environments, some approaches rely solely on software applications to secure assessments. Among these, the Safe Exam Browser is becoming increasingly popular with web-based e-assessments and often is used in conjunction with a Moodle LMS. At the same time, security concerns are risen, and exploitation methods are found, e.g., by Søgaard [5] as well as Küppers et al. [6]. They all conclude that the SEB is insufficient as a standalone measure for e-assessment security and becomes especially fragile with Bring Your Own Device (BYOD) scenarios or take-home exams. Using a kiosk browser like the SEB as part of a larger security concept, however, can be highly beneficial and should be considered when designing an e-assessment environment. Besides technical cheating countermeasures, Apampa, Wills, and Argles [7] further stress the importance of strong user authentication for e-assessments.

Apart from all the technical details, various additional aspects need to be considered when

[1] Safe Exam Browser project website: `https://safeexambrowser.org/` (Retrieved 19.04.2021)

designing and conducting e-assessments. An encompassing overview is given by Vogt and Schneider [1]. This includes among others: didactic properties, technical requirements, and available e-assessment environments. Sauer, Froitzheim, and Hoffmann [8] moreover depict the whole lifecycle of an electronic examination, ranging from initial conceptual work up to archiving of test results. Even though these publications go far beyond the context of this paper, we still recommend taking them into account when developing a comprehensive concept for electronic assessments and designing a respective environment.

3 SOFTWARE ENVIRONMENT FOR E-ASSESSMENTS

At most universities, a large variety of computer labs exist. These include general-purpose workspaces as well as specialized department or topic specific labs, offering from just a few up to more than 100 workstations. Being able to provide a unified e-assessment environment across all labs benefits examinees and examiners alike. As students are familiar with the uniform environment, they experience less technical difficulties and stress during exams. University staff, on the other hand, is able to develop new and re-use existing digital exams independent of the available PC pools and exam supervision is simplified by using a standardized system.

None of the currently available e-assessment environments suits our need for lightweight portability across diverse computer labs. We therefore developed Examuntu, a novel Linux-based operating system that is specifically designed for e-assessments. Its primary objectives are:

a) **Security**, to prevent PC-based cheating and simplify exam supervision
b) **Portability**, so that the system can effortlessly be deployed in varying computer labs
c) **Customizability**, allowing adaption to multiple types of e-assessments, each coming with different types of exercises and a distinct set of software applications
d) **Fairness**, by providing equal conditions for all examinees

3.1 System Architecture

The Ubuntu[2] Linux distribution in conjunction with a lightweight LXQT desktop environment[3] is used as a base system for Examuntu. This allows our environment to perform well, even in labs with older resource-restricted PCs, benefiting the aspired portability. Most OS functions are restricted and a solid web filtering solution is integrated. These components form the core system, which then can be extended according to individual software requirements of specific examinations. A self-contained OS image is semi-automatically generated for every type of assessment. With our scenario, as discussed in Section 4, a lockdown web browser (i.e., kiosk browser) is integrated to allow controlled access to a Moodle LMS[4], which provides the assignments. This yields our system architecture, as depicted in Figure 1.

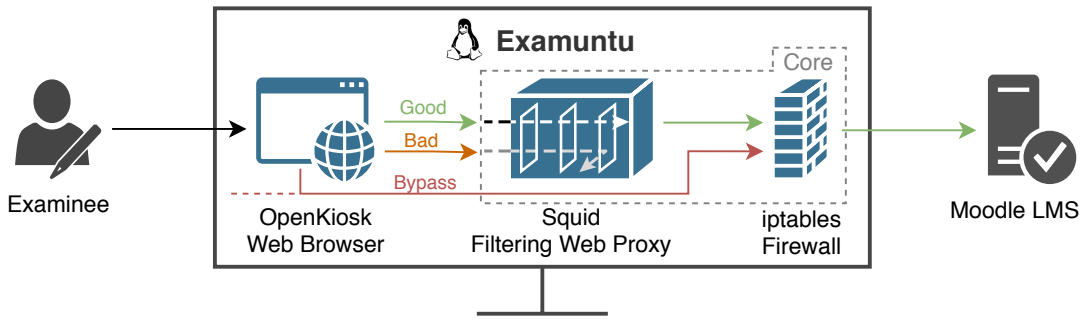

Figure 1: Interaction of the examinee with a Moodle LMS through Examuntu

[2]Ubuntu Linux distribution website: `https://ubuntu.com/` (Retrieved 25.04.2021)
[3]LXQT desktop environment website: `https://lxqt-project.org/` (Retrieved 25.04.2021)
[4]Moodle learning management system website: `https://moodle.org/` (Retrieved 25.04.2021)

During examinations, the OS is centrally deployed via network boot (PXE) as a live system without any persistence (see Section 3.2). This solution not only offers lightweight portability, but also benefits the aspired fairness by reliably providing a clean and identical environment for every examinee. Key aspects, performed adjustments, and technical details of the proposed Examuntu e-assessment environment are discussed within the following sections.

3.1.1 Base System

Several measures were applied to harden the operating system itself. Live systems typically allow the local user to gain system administrator privileges. This permission was revoked and all superfluous software packets, such as the calculator, were removed. Many features of the desktop environment were restricted or completely disabled. This includes the removal of start menu entries, disabling of system settings utilities and tools, removal of virtual desktops, and unmapping of hotkeys, such as `ALT + F4`. Access to internal and external storage media, such as hard disks or USB drives, was prevented by revoking device access and mount permission from the local user. These security measures ensure that the examinee can neither exploit the local operating system nor use external storage devices to exchange data. Additionally, since some PC pools offer multiple displays per workstation, the operating system forces a fixed display configuration at boot, hereby preventing the usage of these additional screens.

3.1.2 Web Filtering

Blocking or selective filtering of outgoing internet traffic is a necessity for an e-assessment environment. Fine-grained traffic control is achieved by using a Squid web proxy[5]. With it, advanced access control lists (ACLs) are used to whitelist websites and services based on their URL, the current time, and various other attributes. This enables assessment developers to selectively allow access to specific websites, network shares, and other network resources, while unwanted web-based tools, such as calculators or messaging services, are blocked. Integrating web filtering directly into our environment not only benefits security, but also further fosters portability by making external and computer lab specific filtering solutions superfluous.

The possibility of forcefully bypassing the filtering proxy, e.g., by modifying the browser network settings or by gaining access to another application, was eliminated through the use of an `iptables` firewall. It was configured to only accept outgoing traffic that originates from the Squid filtering proxy. Hence, all unfiltered traffic, originating directly from the local user and therefore not passing through the proxy, is dropped, as illustrated in Figure 1.

3.1.3 Browser Security Measures

Since controlled access to a Moodle LMS is required by most current e-assessments at the HAW Hamburg, we extended the Examuntu core system with a secured web browser. OpenKiosk[6], a Mozilla Firefox derivative featuring lockdown capabilities (i.e., kiosk mode), was used instead of the commonly found Safe Exam Browser, since the latter only offers support for Microsoft Windows and macOS. Because application access control and network filtering are implemented by the Examuntu core system, the sole purpose of the lockdown browser is to keep the examinee focused on the assessment. The browser was therefore configured to automatically start in full screen mode and prevent application switching. Features such as address and bookmark bars or developer tools were disabled and the browser settings were locked. This yields an uncluttered user interface, leaving the maximum amount of screen space available for displaying the actual assessments. To allow quick recovery from the unlikely case of system failure, a reset button that initiates a clean browser session was integrated.

[5] Squid web proxy project website: `http://www.squid-cache.org/` (Retrieved 25.04.2021)
[6] OpenKiosk project website: `https://openkiosk.mozdevgroup.com/` (Retrieved 25.04.2021)

3.2 Configuration and Deployment

A key design concept of Examuntu is to provide a core system that can easily be customized and extended according to the requirements of different e-assessment types, such as browser-based exams or programming exams that require specialized development environments (IDEs). A semi-automated image creation process is used to build and maintain the different environments. All images share the same Examuntu core system, but differ in the provided software packets. Generated self-contained OS images are stored centrally and get rolled out via network boot (PXE). This allows their use in varying computer labs while only entailing a minimal initial configuration effort, hereby relieving system administrators and simplifying lab reservations. For assessments of the same type, no additional configuration is necessary once deployed. Installation of software updates is accomplished by updating the single central OS image instead of all lab computers individually.

During boot, the OS image is loaded into the RAM of the respective computer, leaving all local disks untouched at all times. As a result, the OS is non-persistent, hereby protecting the lab PCs from modification while also reliably providing an identical and reproducible environment to every examinee. All transferred files are compressed to speed up the system boot process and reduce network stress when starting multiple PCs concurrently. OS size is further reduced by purging caches and other optimizations during release. Once booted, no further traffic to the network file system (NFS) share is required, since the OS is fully loaded during system startup. This not only preserves network bandwidth during ongoing exams, but also enhances resilience against network outages.

4 USE AND EVALUATION

The developed e-assessment environment was successfully tested during multiple examinations at the HAW Hamburg. We start by describing our teaching-learning scenario, the configuration of our Moodle LMS, and our local Examuntu deployment. Subsequently, we evaluate and discuss our experiences and present insights gained from the conducted exams.

4.1 Teaching-learning Scenario and Moodle LMS Environment

Students have to be familiar with both the e-assessment environment in general and individual aspects of the question types, such as the mathematical input syntax. We ensure this by two measures. First, students are familiarized with Moodle by using the online learning environment viaMINT [9] during pre-courses. Second, subject-specific aspects and respective question types are learned with online exercises throughout the entire semester, hereby establishing a well-founded constructive alignment. At the time of examination, all students therefore are already familiar with both the environment and the used question types.

All our exercises and e-assessments were carried out using a Moodle LMS that we customized and extended to our specific needs. The system currently is capable of smoothly conducting exams that feature advanced question types with more than 200 participants. Assessing the equivalence of complex mathematical expressions is mandatory with most of our questions. Besides the default Moodle question types, the STACK[7] plugin was therefore used in conjunction with GoMaxima [10], an optimized Maxima[8] worker pool we developed. STACK features question randomization as well as parameterization and is able to generate individual feedback for every question variant. This not only provides resilience against cheating, but also allows developing exercises that assess higher competence levels. The integrated feedback tree is evaluated for every submitted answer and question variant. It allows both the fractional grading of student responses and the automatic detection of subsequent errors.

[7]STACK question type project website: `https://www.ed.ac.uk/maths/stack/` (Retrieved 26.04.2021)
[8]Maxima CAS project website: `https://maxima.sourceforge.io/` (Retrieved 26.04.2021)

Students are assisted by the platform in two ways when using these complex question types. First, a syntax reference table that contains all required symbols is displayed alongside every exercise. Second, a graphical live preview of the entered mathematical expression is rendered for every formula input field. This allows students to quickly verify that their entered response is correctly interpreted by the system and fosters double-checking of proposed solutions.

4.2 Deployment

The Examuntu environment was deployed and tested in three of our computer labs. Capacities ranged from 55 to 80 workstations each, spread across multiple rooms. Dynamically switching between labs was found to require only minimal effort due to the lightweight and portable design of Examuntu. Initial deployments were completed within less than four hours and the roll-out of updates only required about 15 minutes. Activating the Examuntu environment prior to an exam took less than a minute and can even be further automated. Parallel booting of all computers in a pool took no longer than two minutes.

Prior to all conducted e-assessments, a technical dry-run with a total of 28 computers was performed. Initial NFS performance problems during boot were solved by OS compression and configuration optimizations. Moreover, lab specific details, such as the availability of multiple screens and other peripherals that need to be taken into account, were observed and handled appropriately. For example, an inadequately configured permission that was still allowing access to a subset of storage devices was hereby found and fixed.

4.3 Conducted E-Assessments

We evaluated Examuntu within multiple examinations for students of various mathematics courses at our university. The following types of e-assessments were conducted:

(a) **Intermediate Test**: ungraded, fully digital, 60-75 minutes

(b) **Hybrid Exam**: graded, split into digital and pen-and-paper part, 120 minutes

(c) **Digital Exam**: graded, fully digital, 75-90 minutes

All assessments were carried out in computer labs with workstations spread across multiple rooms. Every room was supervised by a staff member in order to support students and to monitor the exam. Even though all computers were running the secured Examuntu environment, supervision by a staff member was still necessary in order to prevent analog cheating.

A Moodle course, containing only a single test activity, was created for each assessment. Every eligible student received a personalized one-time user account that only allows access to the respective test. Login information were handed out to the students by a staff member after a successful identity verification. Once logged in, examinees were taken directly to the associated assessment. Additional Moodle features, such as personal messaging, forums, or blogs, were disabled. A synchronous exam start was achieved by requiring a simple password to access the test. It was revealed, once every student was ready to begin. After examination, all accounts were frozen and results were exported.

Grading of student responses was automatically performed by Moodle and STACK, but was subsequently reviewed by a lecturer before a final grade was assigned. All results were exported as PDF documents and the Moodle course was hidden and backed up. Generated exports were then handed out to the examiners for archiving. Students could inspect their individual test results by using the accounts that are associated with the respective exam.

4.4 Evaluation

All conducted e-assessments worked very well and revealed neither major problems nor severe technical difficulties. Students immediately were familiar with the exam environment due to the

constructive alignment of our courses. In a qualitative survey, they reported that Examuntu was easy to use and applied security measures caused neither problems nor irritation. The digital workflow was described as simple, supporting and well streamlined. Two students experienced issues while inputting mathematical expressions. These syntax confusions, however, could be quickly resolved by the present university staff during the ongoing examination.

Exam supervisors also benefited from the digital security measures. They reported, that the environment relieved them from digital cheating prevention tasks like monitoring open browser tabs or checking running applications. Even large computer labs could therefore easily be supervised by a single staff member, since solely analog cheating had to be prevented.

The performance of 32 students within digital and pen-and-paper parts for two of our hybrid exams is compared in Figure 2. An examinee that performs significantly different in one of both parts would be represented by a point in either the upper left or lower right corner of a diagram. Results show no such case for both e-assessments. Instead, most students scored slightly better within the digital part. The performance of individual students throughout the semester was also found to be consistent across the different examination types. We therefore assume that Examuntu, despite all applied security measures and restrictions, did not systematically reduce student performance. However, due to our small sample size, differences between student cohorts, and the unclear comparability of exercises, we consider this assumption only a rough indication rather than a confirmation of our hypothesis. In order to reliably confirm it, further systematical evaluations are required.

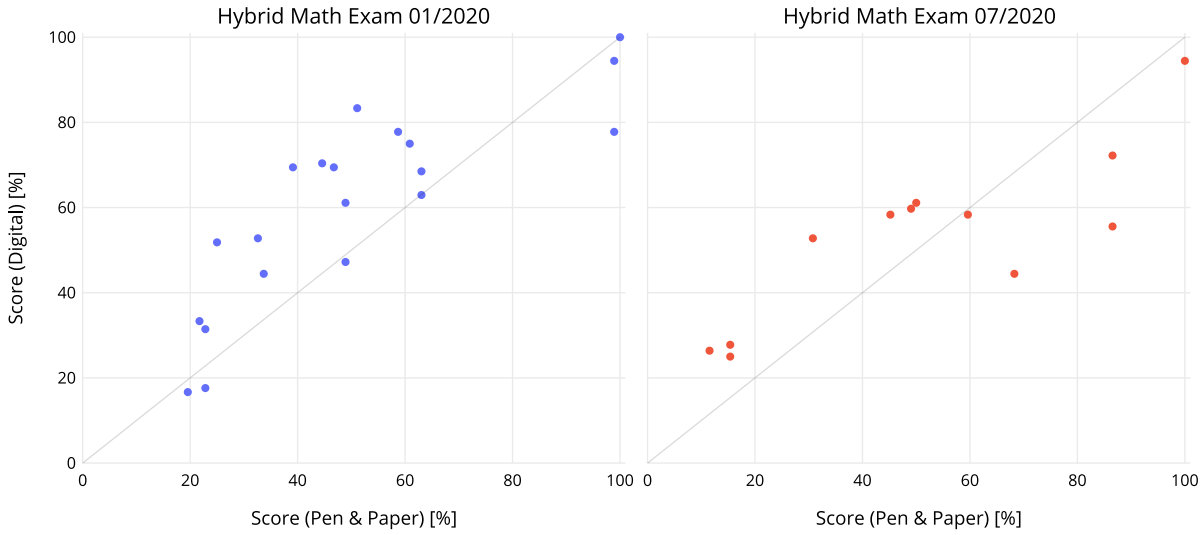

Figure 2: Student performance in digital vs. pen-and-paper parts of two hybrid exams

5 CONCLUSION AND OUTLOOK

With this work we contributed Examuntu, a lightweight, secure, and portable e-assessment environment. We outlined its successful use within multiple examinations. Our qualitative evaluations confirmed, that both examinees and examiner benefit from the novel environment. Applied security measures were furthermore found to have no systematical negative impact on student performance, when compared to other forms of examinations.

Future work includes the integration of different software applications, such as programming environments or MATLAB, as well as improving the configuration management and provisioning process. Dynamically extending lab capacities by using portable laptop computers, running the Examuntu environment, furthermore is part of our agenda.

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