The Virtual Computer Networks Lab

On the Design and Implementation of a Location Independent Networks Laboratory in Higher Education

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Introduction

- The COVID-19 pandemic had a huge impact on teaching!
- Practical laboratories for important lectures became impossible!
- The need for high-quality, flexible teaching solutions that can be accessed anytime, anywhere has never been more urgent!

The Issue

However, the success of these initiatives is critically dependent on the availability of user-friendly IT infrastructures that can adapt to fluctuating resource demands.

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Background

SKILL/VL platform

Motivated by the COVID-19 pandemic, the **Frankfurt University of Applied Sciences** has developed a virtual learning platform for academic teaching in computer science classes. The project SKILL was funded by the **Stiftung Innovation in der Hochschullehre** as part of the program *„Hochschullehre durch Digitalisierung stärken“*.

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Goals

Simplicity Make complex systems and infrastructures usable by students and teachers.

Reliability The platform should be reliable and incorporate long-lasting components.

Usability Creating and using virtual learning spaces so non-IT-savvy users can easily understand them.

Open Source Open source solutions such as KVM (Kernel-based Virtual Machine) and Ceph are used for the platform.

The SKILL platform is available to user groups (students, faculty, and staff) to enhance teaching with a digital offering. Ease of use is a high-priority goal of the platform, as it allows faculty and staff to integrate virtual learning spaces into their courses. The students get tools at hand through the resources of the virtual learning spaces, which enable them to have a new form of interaction.

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Characteristics of physical and virtual lab

The SKILL platform should enable **asynchronous**, teaching **anytime** with **high accessibility**, **low costs** through using open source components enabling **remote work** for students.

Table Source

Alam, A. and Mohanty, A. (2023). *Discerning the Application of Virtual Laboratory in Curriculum Transaction of Software Engineering Lab Course from the Lens of Critical Pedagogy*. In Sentiment Analysis and Deep Learning, pages 53–68, Singapore. Springer Nature Singapore.

Characteristics	Physical Lab	Virtual Lab
Realism	High	High
Content	Stable	Dynamic
Focus on Study	Lecture	Student
⇒ **Form**	Synchronous	Asynchronous
Number of Students	Limited	Without (physical) limits
⇒ **Time**	Scheduled	Anytime
Focus of course	Group	Individual
⇒ **Accessibility**	Low	High
⇒ **Cost**	Very high	Low
Maintenance Effort	Very high	Low
⇒ **Remote Work**	Not possible	Possible

Solutions on the market

Criteria	SKILL/VL	Cisco Packet Tracer	Mininet	GNS3
Open Source	Yes	No	Yes	Yes
Simulator	Yes	Yes	No	Yes
Emulator	No	No	Yes	Yes
Scalability	Yes (by extending the Web service)	No	limited (using more processes)	No
Automatic setup	Yes	No	No	No
Graphical User Interface	Yes	Yes	No	Yes
Extensible beyond Networks	Yes	No	No	No

Comparison of SKILL/VL to exisitng solutions

All the solutions we inspected, except for Cisco, are open-source and free of use. However, GNS3 is the only solution that offers a graphical user interface. This is particularly important as the tool should be accessible to students with little experience in networking technologies. GNS3 has a limitation that it can only be used in computer networks classes.

The SKILL/VL platform should be extensible beyond the computer networks' application field. It should also offer capabilities for use in distributed systems or software engineering classes, for example.

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Project Virtualization of distributed environments for teaching[1]

SKILL/VL

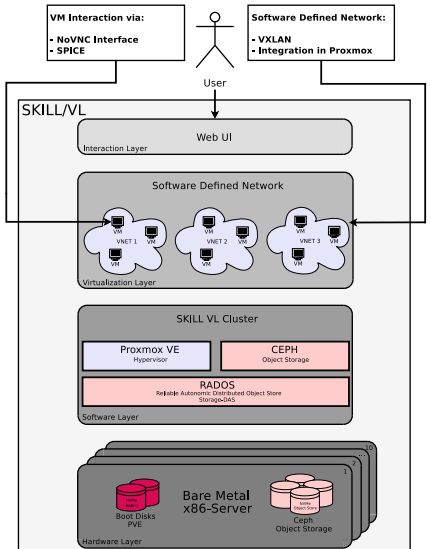
Key features of SKILL/VL plattform[2]:

- Hyper converged infrastructure (cluster of 12 servers)
- Software Defined Storage
- Software Defined Networking
- QEMU/KVM as virtualization engine
- Strict use of open source software:
  - *Proxmox VE* as hypervisor (*KVM-based*)
  - *Ceph* as distributed object storage
  - *QEMU-Guest Agent* integration for configuration of VMs
  - *VXLAN* (Virtual Extensible LAN) integration for (virtual) network configuration

[1] Original: Strategische Kompetenzplattform - Innovativ Lernen und Lehren – Virtualisierung verteilter Umgebungen für die Lehre

[2] `http://www.virtuellelehre.de/`

SKILL/VL Architecture



SKILL/VL plattform:

- **Interaction Layer** – React web UI.
- **Virtualization Layer** – VMs and SDN network environment.
- **Software Layer** – Proxmox VE and Ceph as plattform for virtual resources.
- **Hardware Layer** – x86 server, physical network and storage.

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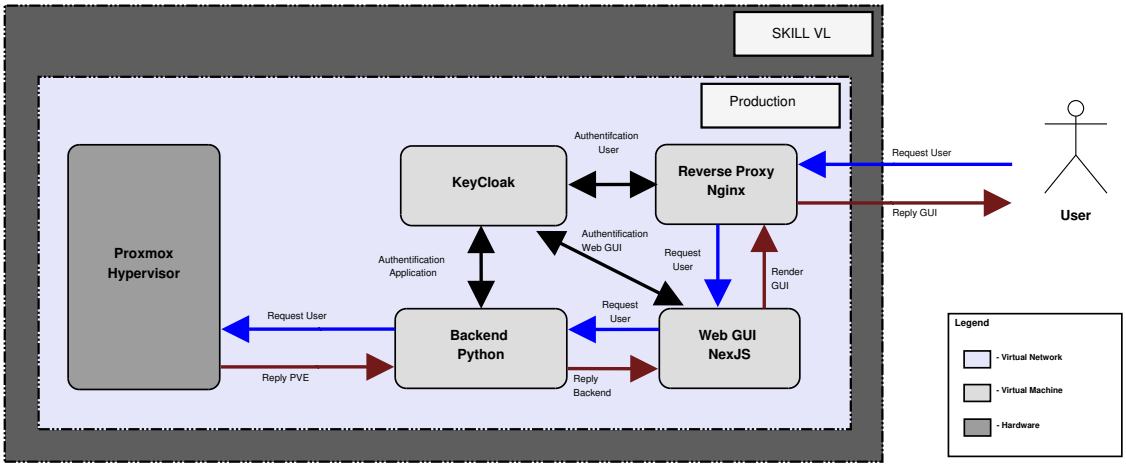
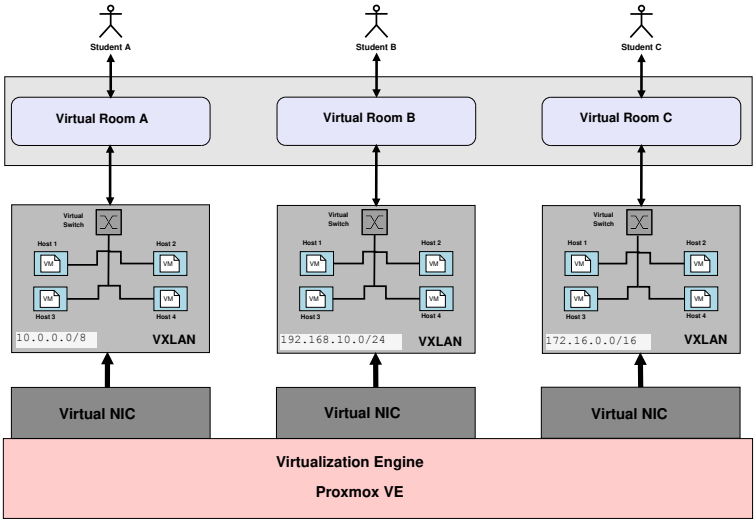
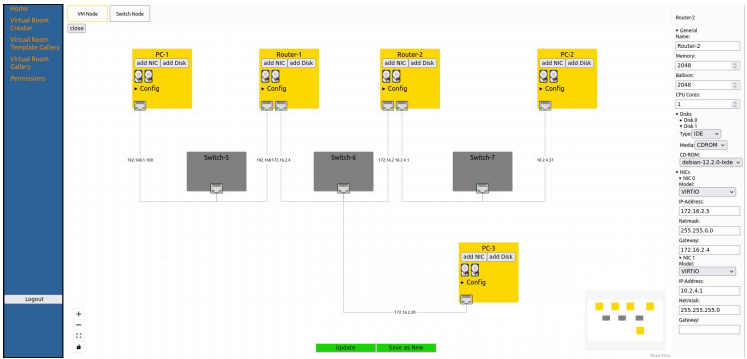
SKILL/VL Architecture – Open Source Software Components



Mapping virtual learning spaces to physical components



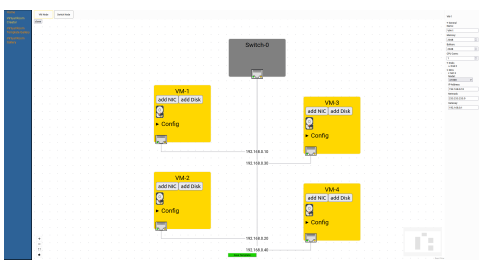
SKILL/VL – SDDC (Software Defined Data Center) 1/2

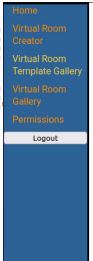


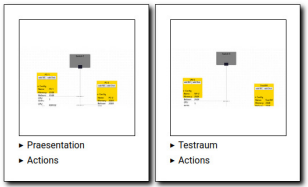
SKILL/VL SDDC:

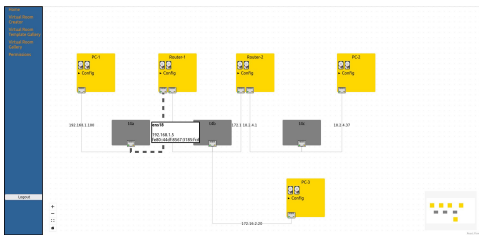
- Creation of complex virtual network scenarios.
- Management of individual permissions of resources.
- Easy configuration of virtual machines over UI.
- Graphical illustration of complex network topologies.
- Easy to understand without knowledge of infrastructures.

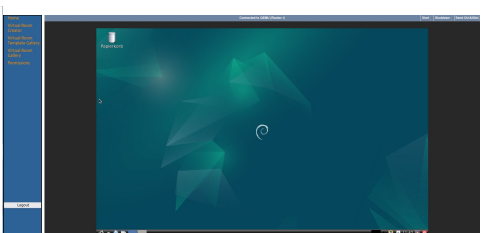
SKILL/VL – SDDC (Software Defined Data Center) 2/2



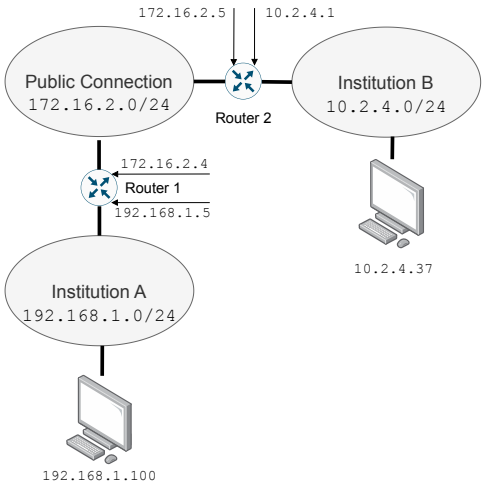








Practical application in laboratories: Computer networks

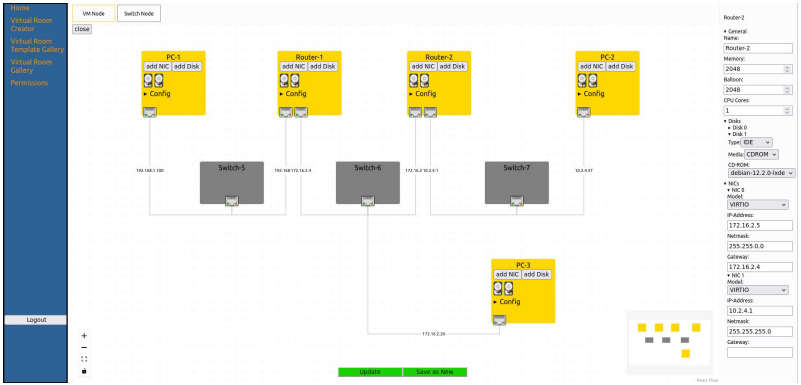


- The public network (`172.16.2.0/24`) as an internet connection.
- Institution A (`192.168.1.0/24`) is connected via **Router 1**.
- Institution B (`10.2.4.0/24`) is connected via **Router 2**.
- Students configure network parameters (IP addresses, gateways, and router settings).
- A web service on the machines communicates with clients via `curl`.
- Another host on the public network is used for testing and monitoring.

Physical setup: LINBO

- 24 individual workstations (each with five Ethernet interfaces) organized into groups of four students.
- Each workstation is connected to a switch linked to a management server via DHCP.
- The management server uses the open-source imaging software **linuxmuster**, automatically deploying OS images.
- Students or teachers select the appropriate image for the exercise, either automatically or manually.

Virtual setup: SKILL/VL



- The setup is either predefined via templates or freely adjustable.
- **Template:** Students select a learning room and start the environment.
- **Free Flow:** Student select an empty learning room and *drag and drop*.
- The SKILL/VL platform starts VMs and components in individual VXLANs.

Benefit

The number of interfaces and components (switches, routers) is variable, and the configuration can be done via the GUI!

Comparison of physical lab vs. virtual lab using SKILL/VL

Characteristics	Physical Lab	SKILL/VL
Images	LINBO	QEMU/KVM
⇒ **Rollout time for images**	30 Minutes	5 Minutes
Rollout of scenario	Time dependent	Time independent
⇒ **Multiple parallel scenarios**	Impossible	Possible
Snapshots	Impossible	Possible
⇒ **Time**	Scheduled	Anytime
Separation of networks	Whole lab	Individual group or student
⇒ **Separation on OSI layer**	Layer 3 (IP)	Layer 2 (VXLAN)
⇒ **Accessibility**	Low	High
⇒ **Remote Work**	Impossible	Over ordinary web browser

Conclusion

The SKILL/VL platform has a **6-times** faster setup time! It also allows for the **parallel rollout of multiple scenarios**. Additionally, unlike the physical lab, SKILL/VL's use of VXLAN provides **logical separation of networks at layer 2** of the OSI stack. Also, the maximum capacity for the lab is increased by a **factor of 6.25** (⇒ **24 vs. 150 clients!**) through the use of virtualization!

Conclusion

- The feasibility of the project was demonstrated, and the proof-of-concept was successful!
- We successfully evaluated the web interface and the setup of the underlying infrastructure.
- The productive use and integration of the platform in various courses are an ongoing process.
- Further monitoring through performance measurements and evaluations is planned to obtain data on the technical characteristics.

Summary

Developing and implementing a virtual learning platform for university teaching, which in particular allows creating and using complex IT structures for non-experts in teaching, was a success using only free software.

Future Work

- Improving the accessibility of the user interface following Web Content Accessibility Guidelines 2.1 (WCAG) guidelines.
- Expanding the platform's capabilities includes offering various Linux distributions.
- Refactoring software toward a container platform will boost efficiency and speed up release cycles using a cloud-native setup.

Thank You For Your Attention!

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