LiLa: A European Project on Networked Experiments

Th. Richter[1], D. Boehringer[1] and S. Jeschke[1]

[1] Universität Stuttgart/RUS Computing Center, Stuttgart, Germany

Abstract—**The LiLa project – short for "Library of Labs" – is a European Community funded project to network remote experiments and virtual laboratories. The goal of this project is the composition and dissemination of a European infrastructure for mutual exchange of experimental setups and simulations, specifically targeted at undergraduate studies in engineering and science. This article discusses the architecture of the project, introduces its components and sheds some light on our motivation and background.**

Index Terms—**Remote Experiment, Virtual Laboratory, Automated Course System**

I. INTRODUCTION

Hands-on courses are – in addition to lectures – one of the fundamentals of engineering education. Students learn here how to solve practical problems, and delve into experimenting with real equipment. Besides theory and practical experiments, simulations also become relevant in science and engineering; increasing costs force engineers to substitute expensive or complex experiments by simulations – sometimes not even to cut costs, but also to gain insights not or only hardly achievable due to physical constraints otherwise.

However, increasing complexity also limits the ability of universities to fund courses on such matters, and often we find the situation that only a limited number or a limited corpus of experiments can be made available for student labs. To address this problem, universities setup – now and in the past - *Remote Experiments* and *Virtual Laboratories*. While the former are "real" experiments that are, however, remotely controlled over the internet, the latter are highly flexible environments to run simulations. Both enable students to make use of the equipment 24h/7 days a week, making them independent on the opening hours of the lab and the work schedule of the staff.

Up to now, most of such solutions were restricted to single universities or institutions – for a couple of noteworthy exceptions, see the next chapter. That is, the equipment and software available has been limited by the abilities and funding of the controlling institution. However, since said experiments are *by construction* available over the internet, an obvious improvement of this situation is to found a federation of supporting institutions, and allow students mutual access to the equipment available in this federation in total: This is the major goal of the LiLa project, namely to setup a *Library of Laboratories* across Europe, and to share resources available in this network. LiLa is funded by the European Community by its eContent*plus* program.

However, goals of this project go beyond generating the software necessary to setup said network: its aim is not only to share and increase the utilization of the equipment, but also to help students to *find* the experiments they need, to integrate the experiments into electronic library catalogs, to link them to "traditional" media as for example lecture notes, and to equip and extend the experiments by courses build from this media; last but not least, an important further goal of LiLa is to integrate such interactive courses into the curricula of universities.

Clearly, to make this vision to become true, contracts and legal side-conditions must be worked out and understood, and LiLa attempts to provide contract-templates to make it as easy as possible for interested partners to join the consortium.

This article is structured as follows: We will present some related projects in the next section and discuss similarities and differences between them. Following that, we introduce the architecture of the LiLa project and give some examples of the existing content. We close by a conclusion.

II. RELATED WORKS

A project similar to that of LiLa is driven by the MIT in the USA: Similar to LiLa, the *iLabs project* [1,2] supported by Microsoft aims at making experiments remote-controlled, and thus having them accessible by web-services for other members over the internet. In fact, one of the LiLa members, the University of Cambridge, is already participating in the iLabs project, and we aim to cooperate with iLabs in a long term perspective. Very similar to iLabs, LiLa is not focused on a specific topic, but addresses bachelors in all engineering and scientific studies. Similar to iLabs, we aim at a "single sign on" process to gain access to our resources. This process will be integrated into the Wonderland architecture (see below).

The Blekinge Institute of Technology in Sweden started in 2007 the *VISIR project* [3], which is, however, unlike LiLa not supported by the European community. Quite similar to LiLa and iLabs, VISIR tries to increase laboratory utilization by sharing remote-controlled equipment across universities. Another similarity is that this, and many other projects [5,12] deploy the LabView software by National Instruments to wire experiments to the internet.

A. Differences and Concepts

Despite all similarities, some major differences exist between the projects introduced above and LiLa: the driving motivation of LiLa is to establish remote experiments and virtual laboratories as a core component of engineering education, to integrate them as such into the curricula and to share those materials with others all over Europe - and even beyond. For the achievement of this goal, didactical guidelines are developed, a portal for the access to remote and virtual experiments including an access control and scheduling system is set up, and the experiments are enriched with "traditional learning material" like lecture notes and recordings, exercises and assessments, and content the libraries can provide. As learning assistance, a tutoring system allowing individual learning paths is guiding students through the material. Last but not least, the virtual world Wonderland supports the LiLa architecture by providing a framework for collaboration: fostering the cooperation between students working on experiments is of special concern to our project, and we see it as one of the most important non-technical skills trained in "traditional" laboratory courses. We believe that LiLa goes beyond comparable projects due to this comprehensive approach.

III. THE LiLa ARCHITECTURE

The LiLa architecture is structured in four tiers or layers, see Fig.1: The lowest tier consists of the *content*, where we understand the content to include remote experiments and virtual laboratories – and not only to consist of static documents. All content modules are to be annotated by suitable metadata to make them locatable and available, and to allow their integration into library catalogs. Of course, we cannot expect that a metadata system like the DDC notation originally developed for static documents to be suitable for interactive components; to this end, the design or extension of a metadata system is one of the tasks within LiLa.
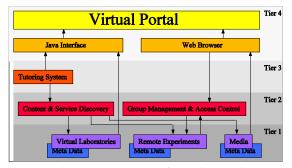

Fig 1: Architecture of the LiLa Project

The second tier ensures accessibility of the content: On one hand, content (i.e. experiments and static data) must be locatable within the pan-European LiLa network. That is, we want to enable students and researchers to search for content available at participating members that satisfies their needs, similar to the way how a library catalog is used to locate suitable books. On the other hand, remote experiments – unlike simulations – are also a resource with limited availability that needs to be shared fairly between users and for which varying access policies must be established. The second tier thus includes a booking system granting access to the content, and controlling the privileges of the users.

The third tier is responsible to integrate experiments and documents to interactive courses and implements an interactive and intelligent course system that guides students through an – real or virtual – experiment. A prototype of a corresponding system has already been developed at the TU as the outcome of earlier projects, and is currently rolled out at the University of Stuttgart. Further details on *Marvin* and on its learner- and course model are found in chapter IV and in [10].

The user interface as forth layer will be represented by and in the virtual world of Wonderland by Sun Microsystems. Wonderland has been originally developed to ease the cooperation of home-office workers; its purpose in LiLa is to integrate the experiments, courses and documents into a consistent virtual environment, and make equipment, represented by virtual objects, available to the users´ avatars. Due to the rather tight development plan, a two-dimensional projection of a traditional user-interface must be sufficient in the first project phase. Alternatively, we plan a traditional web-front end for experiments, thus the web-browser becomes the user interface.

IV. EXAMPLES AND COMPONENTS

A project of the given size cannot be constructed from scratch; instead, our target is to use existing components as far as possible, and to reach the project goals by merging existing solutions. This is also required by the eContent*plus* programme of the European community, which targets at making existing content more accessible.

A. Remote Experiments

The first type of content made accessible by the LiLa network is that given by "Remote Experiments": A remote experiment is an experimental setup controlled by a common PC; by appropriate software – typically LabView[4] by National Instruments – sensor data and control parameters of the experiment are made accessible over the internet. Remote experiments are already deployed at our project parters in Berlin, Cambridge and Basel.

An experiment from thermodynamics run at the TU Berlin may aid as an example: A motor controls the position of a piston in a glass cylinder, expanding or compressing the gas contained within. An electrically controlled valve enables users to fill the cylinder with air, and a heater can be turned on to change the temperature of the gas volume. A pressure sensor measures the pressure of the gas. All actors – the motor, the valve and the heater – are steered by LabView; similarly, all sensors are wired to the PC making sensor data available to the user. The LabView front-end bundles sensor and actor data, and an additional web-cam allows users to observe the movement, cf. Fig. 2.

In a typical experiment, the student first opens the valve and fills the cylinder with air; afterwards, the valve is closed and the moter is run to compress the isolated gas volume - by that, pressure increases. By turning the heater

on, temperature is increased as well. If the contained air is now allowed to expand again by moving the piston out of the cylinder, pressure decreases again, but will not reach exactly the same value as it had before compression - this only happens after allowing the gas to cool down. By plotting the pressure over the volume in a so-called pV diagram, one observes that the pressure-volume state of the gas in this process forms a closed loop, and one can now show theoretically that the area enclosed by this loop is proportional to the amount of work performed on the gas – and is thus given by the electrical work of the heater.

Experiments similar to the one described above are part of the experimental corpus of every undergraduate engineering course. At the TU Berlin, it is not unusual that more than 1000 students per semester participate in courses on experimental physics.

Fig.2: A remote experiment on phenomenological thermodynamics. Left: A piston compresses air in a glas cylinder. A heater (below) controls the temperature of the air. Pressure and temperature are measured by the PC. Right: The LabView user interface of this experiment.

B. Virtual Laboratories

Unlike remote experiments, virtual laboratories are simulation frameworks that run on the computer only and do not interact with a physical experiment; even though one could simply ask students to install the simulation software on their home PC, we prefer to use a client-server model here as well. First of all, the amount of work for installation is minimized, but second – and even more important – the server architecture allows students to interact with each other and collaborate on one simulation. An example for a virtual laboratory is "VideoEasel", currently deployed at the University of Stuttgart, a simulation framework for experiments in multi-particle physics. Further virtual laboratories are provided by our partners in Basel, Cambridge and Linköping in Sweden.

A virtual counterpart of the above experiment on thermodynamics can be realized in VideoEasel, cf. Fig. 3:

The laboratory simulates here an idealized and simplified gas, a so-called lattice gas [8,9]. In a typical experiment, the student first draws a gas container, and fills one edge of this container with particles. A sensor measuring the entropy of the gas volume is then added to the simulation – the entropy is a physical quantity measuring the amount of disorder of a multi-particle system. When running the simulation, the gas spreads out into all of the container, and by that increases the entropy – following the Second Law of Thermodynamics.

While this is clearly to be expected, one can now extend this experiment in a way that is not possible in reality: by inverting the velocities of all gas particles, the movement is inverted and the gas flows back to its initial location by decreasing the entropy. It is now interesting to let students discuss why this movement, while possible by the laws of physics, cannot be observed in reality.
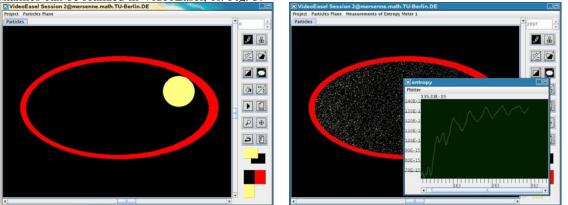

Fig. 3: A virtual experiment on the Second Law of Thermodynamics. Left the initial state with the gas (yellow) in one corner of the container (red). Right the final state after running the experiment for a while, also showing the entropy over time.

C. Tutoring Software and Intelligent Assistants

Running complex experiments usually requires students to consult an experienced fellow student or an assistant. However, in order to help students to experiment outside of the regular opening hours of labs, simulations and remote experiments are equipped and extended by electronic course systems that guide users through an experiment. An example for such a course system is given by the "Marvin" system, originally developed for VideoEasel[10].

A course within this system is understood to be built from "learning units", where each learning unit encodes both its contents and the perquisites a student must have to be able to follow it, cf. Fig. 4.
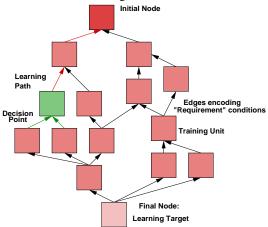

Fig. 4: Path model of a course, consisting of learning units. Arrows indicate dependencies between units, from the goal to the initial node. Students follow the course in opposite direction, resolving prequisites first. On the left: A decision point (green).

The course system is now responsible to resolve all dependencies by constructing a suitable learning path – defined as a sequence of learning units of a course. To evaluate the learning success of a learning unit, Marvin uses a plug-in mechanism that links code at run-time to the experiment to evaluate the user behavior there, and to feed back the results into the course system.

In addition, Marvin uses a statistical approach to optimize the learning strategy: This mechanism is used whenever more than one learning path connects the current node with the final learning goal, i.e. whenever the system reaches a decision point (the green node in Fig. 4). At those points, Marvin recommends either one or the other node depending on which maximized the learning success in the past on average. For more details, see [10].
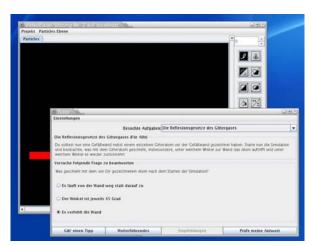

Fig.5: A screen shot of the virtual laboratory with the tutoring system in a separate window on top. Here an experiment on reflection.

D. Cooperation in Virtual Worlds

The user interface of most experiments and simulations remains necessarily abstract and reassembles the look and feel of a real laboratory only to a very minor degree. Specifically, a real lab allows students to communicate to each other and to cooperate in performing a course. Unfortunately, this important element often under-estimated in similar projects, even though it is very relevant for the working engineer or scientists: Teamwork is the common practice given the complexity of today's technology.

Sun Microsystems "Project Wonderland" [6,7] has been developed with quite similar applications in mind, namely to allow and foster the cooperation of teams of home-working employees in companies. Within the LiLa project, Wonderland will be user interface and primary access tool for the experiments provided by the network.

Fig. 6 demonstrates a typical look of the virtual world: Colleagues, represented by avatars, move around in the virtual world and can talk to each other, by using the built-in voice over IP functionality. Simulated projection surfaces allow running presentations or embed "flat" desktop programs into the world.

Fig. 6: Screen shot of Wonderland: Avatars in front of a projection surface of an embedded web browser (Source: Sun Microsystems).

In the LiLa project, we will aim at constructing virtual three-dimensional representations of real experiments that are close to look and feel, but due to time constraints, only

flat two-dimensional representations as those shown in Fig. 6 will become available in the first project phase.

V. PARTNERS AND ROLES

The LiLa consortium consists of eleven institutions from seven European states: the University of Stuttgart, the initiator and coordinator of the project; the Institute of Technology (TU-Berlin), the Universities of Basel, Cambridge, Linköping and the Aristotle University of Thessaloniki contribute their remote experiments and their virtual laboratories – namely content – to LiLa. Thessaloniki is furthermore responsible for the evaluation of the project results.

The University of Delft is our key partner for didactics: they are responsible for the didactical preparation and evaluation of the project results. The Universidad Politécnica de Madrid is responsible for developing and implementing the access control system, i.e. tier 2 in Fig. 1. The second activity in that tier is the development of the localization services and the embedding of the content into library catalogs by link-resolver technology, which is the responsibility of the Library of the University of Stuttgart.

Three non-academic partners contribute their technology to the project: First, Sun Microsystems (now Oracle) support us in enhancing their Wonderland technology (see section IV.D) for the needs of LiLa; Computational Modeling Cambridge, a spin-off of the University of Cambridge, develops simulation software for virtual laboratories and will contribute their developments to the LiLa network; and finally MathCore Engineering from Linköping, which is our 3D expert, will develop the virtual 3D models of the experiments and will design the virtual world of LiLa.

A. Work Packages and Partners

The LiLa project is structured in six work packages, each of them consists again of several tasks; every work-package is managed by one of the consortium members, even though the tasks within a work package might be handled by members different from the work package leader.

In detail: The first work package is the management and monitoring of the project as a whole, which is in the responsibility of the University of Stuttgart; the virtual world and its interfaces, the access control and booking system are designed in the second work package by the University of Madrid. Didactical models, the design and evaluation of interactive courses and course materials is in the responsibility of the Technical University of Delft, where some components are also created in Stuttgart, namely the course system described in section IV.C.

The fourth and largest work package is managed by the Institute for Technology Berlin (TUB): This work package integrates existing content into the LiLa architecture, where content is not only understood to consist of interactive experiments, but also includes "more traditional" material like lecture notes and scientific publications. In this work package, we will also design a meta-data set suitable for the annotation of interactive material; this specific work lies in the hands of the Library of the University of Stuttgart.

The fifth work package monitors and evaluates the project results from the scientific and didactical view point; the work package leader is the University of Thessaloniki, even though Delft will run the didactical evaluation as part of this work package.

Last but not least, the sixth work package disseminates project results, is responsible for making project results visible by publications, and will also offer training courses and material for lecturers, students and university administrations to aid them in setting up, running and using remote experiments and virtual laboratories. An important task of this package is also the development of a contract template to ease interesting parties joining the network; legal constraints for exchanging resources between universities need to be identified, and a legal framework for shared resources needs to be worked out here. It is interesting to note that we found in a preliminary questionnaire that most universities do have as much trouble in earning money by sharing experiments as they have in spending money for it. Thus, mutual exchange of resources is likely the model to be implemented.

VI. CONCLUSIONS

Even though LiLa is an ambitious project for constructing an infrastructure for "virtual" experiments, we want to stress that it is not our aim to **substitute** traditional hands-on training; the value of such courses lies beyond the gained scientific insight, namely in getting acquainted to laboratory equipment, and in training the social communication skills with fellow students, colleagues and tutors. Even though we try to mimic these structures as far as possible in the virtual world, their replication remains necessarily incomplete.

Instead, we hope that LiLa makes the best out of the financial problems universities have to face – and establishes a strong federation of universities which, as a group, are able to support their students better than a single isolated institution could.

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AUTHORS

Th. Richter was with the TU Berlin. He is now with the Computing Center of the University of Stuttgart, 70550 Stuttgart, Germany (e-mail: richter@rus.uni-stuttgart.de).

D. Boehringer, is the team leader of the "New Media for Education and Research" group of the Computing Center of the University of Stuttgart, 70550 Stuttgart, Germany, (e-mail: boehringer@rus.uni-stuttgart.de).

S. Jeschke is the head of the Computing Center of the University of Stuttgart, 70550 Stuttgart, Germany, (e-mail: jeschke@rus.uni-stuttgart.de).