NETWORKED EXPERIMENTS IN COOPERATIVE KNOWLEDGE SPACES

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ABSTRACT

Cooperative knowledge spaces create new potentials for the experimental fields in natural sciences and engineering since they enhance the accessibility of experimental setups through virtual laboratories and remote technology, opening them for collaborative and distributed usage. A concept for extending existing virtual knowledge spaces for the means of the technological disciplines (ViCToR-Spaces- *Virtual Cooperation in Teaching and Research for Mathematics, Natural Sciences and Engineering*) is presented, and the integration of networked virtual laboratories and remote experiments ("NanoLab Approach") is described.

1. INTRODUCTION

Focusing on the social aspects of communication, coordination and cooperation, cooperative knowledge spaces possess a high potential to support the learning, teaching and research processes at universities by the means of new media and new technologies. "ViCToR-Spaces", currently under development at the TU Berlin, focus on the enhancement of virtual cooperation in teaching and research in the fields of mathematics, natural sciences and engineering. Therby, they are designed to present novel collaborative working environments for knowledge gain and research as well as supporting natural forms of scientific and technological cooperations, in particular regarding the coollaborative performance of experiments.

Cooperative knowledge spaces use a generalized "room-metaphor" as a guiding line. They provide a virtual meeting place where the interaction, communication and collaboration takes place. The environment as a whole is defined by the combination of its dynamically linked objects, i. e. members, documents, tools and services [1]. Two main types of eLearning and eResearch environments can be categorized: Within *content-oriented system architectures*, the content defines the center point of the system design, communicative and cooperative scenarios are missing or developed around the content objects. In *community-oriented system architectures*, communication and cooperation processes and workflows between the users are the main focus of the system design while content objects are embedded into the "cooperation infrastructure". As of now, content-oriented systems present the more "common" approach, and they form the basis of most eLearning platforms currently available. Community-oriented systems can be regarded as part of the research field of CSCW/CSCL (Computer-supported Cooperative Work/Learning, [2, 3]). Within this approach, social processes, represented by communication, coordination and cooperation, form the basis for successful knowledge gain in education as well as in research. Since this view is becoming increasingly accepted for computer-supported models of education and scientific work, community-oriented systems are currently under intense development.

2. ViCToR-Spaces – COOPERATIVE WORKING ENVIRONMENTS FOR NATURAL SCIENCES

A wide variety of CSCW environments has been developed during the last 15 years and many noteworthy results have been achieved. However, the specific requirements for cooperative knowledge spaces for mathematics and natural sciences [4] are not – or only rudimentally – supported by these solutions. This is probably the main reason for why there are still no satisfactory developments promoting community building and virtual cooperation in those disciplines.

ViCToR-Spaces focus on community-oriented eLTR-strategies (eLTR := eLearning, eTeaching and eResearch) in the fields of mathematics and natural sciences. In order to avoid "reinventing the wheel", they are built on top of an existing CSCW/CSCL platform. As of now, the *sTeam* platform [1, 5] – an open-source environment for virtual knowledge spaces developed at Paderborn University – serves as the base for ViCToR-Spaces. It provides several different mechanisms to support cooperative and communication oriented work and learning processes. Within sTeam, students and teachers meet in virtual knowledge areas for storing and manipulating shared documents. Access rights management mechanisms such as defining user groups, and group permissions contribute to this open and cooperative way of dealing with learning material. Since sTeam permits self-administration, it facilitates the creation of knowledge structures specific to single groups and individuals, thus helping to build virtual communities.

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Integration of virtual labs and remote experiments and the *realization of cooperatively-runned experiments* form one of the most important aspects and are described in section 3 in detail. In the following, additional, special requirements for ViCToR-Spaces are briefly discussed which result from the daily practice of students, teachers, researchers and users of mathematics and natural sciences.

Support of special notations (math./chem. formulae) within all tools:
When exchanging mathematical knowledge in a web-based CSCL or CSCW system, one of the problems most likely encountered is the limited support for writing anything other than plain text. Special notations such as mathematical formulae (where, besides special characters, fractions, sums, integrals, superscripts, subscripts etc. are needed) or diagrams (e. g. UML) cannot be readily entered into forums, wikis or chat systems. These tools have to be extended to support MathML which has been developed for the professional presentation of mathematical formulae at websites.

Authoring tools with MathML support, based on LaTeX, incl. WYSIWYG front-ends:
The editing process for formulae encoded in MathML still represents a complex task which has to be supported by suitable authoring environments. These editing tools should be based on common standards such as LaTeX where possible because of being well-accepted among mathematicians and users of mathematics, and also because of the variety of existing LaTeX-to-MathML converters. However, since competence in LaTeX is far from universal, especially among students, an integrated graphical tool (WYSIWYG front-end) for editing mathematical formulae is an important extension for interdisciplinary cooperation within virtual knowledge spaces.

Distributed field-specific editing on shared chalkboards:
The traditional way of cooperation between mathematicians or natural scientists uses face-to-face communication, where two or more scientists discuss a formula, develop a proof, draw a schematic diagram for an experiment together on a chalkboard or a chalkboard, each of them writing their annotations between their co-researcher's writings. This way, of course, requires each of the participants to be at the same place at the same time. Shared chalkboards represent an approach to overcome geographical distances. Generally speaking, shared chalkboards serve as a common workspace for all members of a group – e. g. the aforementioned mathematicians developing a proof cooperatively. Thus, all members of that group can work on the same set of data synchronously. The chalkboard itself is a virtual or real drawing board on which objects are displayed graphically and can be manipulated. Very much like a chat client, the data which users are working on is displayed identically on each user's chalkboard. For both synchronous and asynchronous distributed cooperative writing, some sort of rights management is essential. Likewise, both forms of distributed cooperative writing require a suitable version management which allows tracing back changes and, if necessary, reverting a content item or a chalkboard session to an earlier state.

Integrating existing eContent from various repositories:
Plenty of eLearning content (eContent) material has been developed in the fields of mathematics, natural sciences and engineering, mostly in previous projects on a local or national level, driven by individual researchers and their institutes. This material is not restricted to text-based knowledge elements, but includes a large amount of multimedia objects and interactive components instead. So far, these resources are widely spread, stored in local databases of eLearning and eResearch projects only accessible to small, restricted user communities. In the meantime, however, the development of appropriate metadata formats and other standardization efforts have provided the means to build large, comprehensive knowledge repositories.

Information Retrieval:
Since such content repositories mentioned above consist of a huge number of elements, automated information retrieval systems capable of handling text, sound, images, data and other objects are becoming more important. So far, web search engines such as *Google* are the most visible applications of research on information retrieval. To handle scientific and educational material, advanced search mechanisms are needed which are capable of interpreting the content of an object in a more comprehensive manner. Semantically enhanced information retrieval techniques are being developed which are usually based on computer linguistic analysis combined with statistical methods.

Apart from the mentioned field-specific demands, current implementations of virtual knowledge spaces suffer from a "lost in cyberspace phenomenon", which has to be addressed by continuative actions towards user support. This includes enhanced transparency of the structure of the virtual space, further development of awareness components for community support, the transparency of workflows for different types of actions, transparency of content management through ontologies and intelligent semantic retrieval mechanisms. Possible solutions to these questions will be discussed in a subsequent paper.

3. EXPERIMENTS IN VIRTUAL SPACES – THE NanoLab APPROACH

Experiments form an important part of learning, teaching and research within the technological disciplines. Integrated into a cooperative knowledge space, they provide better access to experimental setups for all students, independent of limitations in time, budget or access to classical laboratories– thus forming one of the most important parts of the ViCToR-Space concept:

To enhance access to experimental setups, there are two principle alternatives [6]: Virtual laboratories and remote experiments form the basis for the NanoLab-project. Virtual laboratories use the metaphor of a "real" scientific laboratory as a guiding line [7, 8]. The software design focuses on emulating scientific hands-on experience in virtual spaces. In theoretical fields such as mathematics and theoretical physics, virtual laboratories have revolutionized education and research as they allow an intensive experimental access to abstract objects and concepts. They are capable of building bridges between the theoretical fields and experimental sciences. Complementary to virtual laboratories, remote experiments are real experiments, remotely controlled by the experimenter from outside the laboratory [9]. They are based on a technology which allows true experimenting from a remote location at almost any given time. The different approaches have a number of similarities, and enrich each other through their differences: remote experiments allow the investigation of real objects including hands-on measurement experience, which does obviously not hold for virtual laboratories. On the other hand, virtual laboratories are capable of constructing an experiment, whereas this kind of flexibility is hard to imagine or implement in remote experiments.

Designing and implementing a service-oriented infrastructure, targeting on distributed collaborative composition and execution of experiments in natural sciences including data analysis, interpretation of the results, and development of applications is the overall objective of the NanoLab approach. A common portal infrastructure will enable access to virtual and remote experiments in Europe through standardized interfaces. In NanoLab, experiments (regardless of whether they are remote experiments on real physical devices or virtual experiments that are simulated or combinations of both) can be seen as complex processes that consist of various technical and non-technical components (devices, sensors, effectors, analytical components, software services, humans etc.). These components need to be orchestrated into a complex system to perform an experiment. In general, such systems might be distributed. Components of experiments are reusable within other experiments and exchange happens even across different scientific communities that are working on the NanoLab platform. The NanoLab faces a severe heterogeneity challenge: a community driven NanoLab has to enable different providers to design and implement single elements which can be combined with already existing tools within an experiment. Thus, ensuring interoperability across the platform is a non-trivial but very important task. The set of available components for experiments has to be dynamic: new components will be invented by providers and advertised within the platform whereas other components that might be outdated or (in the case of physical devices) temporarily not available will be removed from the platform. Thus, the NanoLab platform can be considered an open marketplace for experimental components.

The organization of all cooperative processes plays an important role within the NanoLab concept. A scenario of collaborative work involving instantaneously connected mobile users in virtual knowledge spaces is structured according to the three phases: Formation (establishing the network infrastructure and group structure), collaboration (structuring and organizing knowledge), and closure (retaining the results). Collaborative work in knowledge spaces connotes creating, sharing, and structuring of results and documents in various ways. Collaborative composition of documents in a Wiki-style manner can be as much part of the collaboration as can the usage of chalkboards or any other mode of synchronous and asynchronous cooperation. The collaboration phase of an ad-hoc group is characterized by the exchange and structuring of materials within the mobile knowledge space. For this purpose the attendees insert documents into the knowledge space to share them with the group. The collaboration may happen synchronously by using a shared chalkboard presenting a shared view to the knowledge space. Similar to scientific practice in a laboratory, the group members can cooperatively explore interactive experiments placed in the knowledge space and develop formal representations of the experiments.

The change from synchronous to asynchronous cooperative work in mobile collaboration scenarios is often seamless. While face-to-face cooperation is the natural form of collaboration in mobile scenarios, the participants may leave the collaboration session. Thus, mobile forms of virtual knowledge organization provide additional challenges to CSCW systems. Classical, centralized collaboration systems have always provided their service via a dedicated server. In the novel distributed collaboration systems, services are provided by several nodes of a peer-to-peer network with all participants being mobile. Small or larger groups establish ad-hoc collaboration networks. Meanwhile users join existing networks for some period of time and then leave again. The classical separation of service provider (server) and service consumer (client) dissolves. The technical terminus "peer" becomes a terminus for a special form of collaboration by sharing collaboration services and resources with each other.

Interconnectedness of the different laboratories and experiments and their embedding into the ViCToR-Spaces is not to be restricted to the purely technical level of IT-integration, but has to include networking on the content level through field-specific ontologies, Semantic Web technology and innovative models of dynamic semantic process composition. Thus, the ViCToR-Spaces have to provide a virtual environment in which collaborative efforts like knowledge distribution and cooperative experiments in nanoscience will be managed intelligently. Semantic Web technologies form the basis to achieve these goals: The Semantic Web aims at augmenting the existing World Wide Web with machine-readable semantics, making the content of today's Web accessible to intelligent queries and machine reasoning. Taking a more abstract perspective, Semantic Web is concerned with the semantically meaningful and well-defined description of abstract resources, for instance documents, graphics, data streams etc. which allow machines to access and deal with abstract resources. In contrast to standard (i. e. not semantically annotated) resources, semantically annotated resources can be integrated automatically and processed dynamically (without deep and detailed prior agreements between the providers of different resources). Effectively, this means that such resources can be integrated across time and communities in a flexible way. This is particularly important for open systems that have many contributors from various communities and systems that change their structure and configuration at runtime. The NanoLab platform as envisioned in this concept is a perfect example of such a system.

4. OUTLOOK AND CONCLUSION

In the past years, the main focus in developing eLTR-technologies has been on stand-alone applications and solutions for specific tasks. Today, modern approaches in the design of the architectures required show that the integration and interconnection of independent, single components occupy a central role in providing diverse, comprehensive functionality and addressing a broad, heterogenious user spectrum.

As a result, we face two serious challenges: First, the next period in information technology will be dominated by demands for application integration. Research and applications are increasingly oriented towards semantic content encoding as a prerequisite for interconnectedness on a content level and towards integrative technologies for software components as "Web Services/Semantic Web". Second, integration on a social, community-oriented level, that is, support of communication and cooperation structures and shared workflows, is becoming more and more important. The human desire for communication and cooperation – as a basis for successful knowledge gain – has been largely deferred in favor of self-determined, independent of time and location learning and working. Not realizing that communication and cooperation in a virtual world will even facilitate one's need for mobile and freelanced access to knowledge gain we currently face a knowledge landscape of spreaded developments and unequally distributed knowledge.

Crosslinking existing knowledge repositories and developments will open knowledge and technologies to students, teachers and researchers beyond geographical limitations by advancing the building of virtual communties. Instancing ViCToR-Spaces combined with the NanoLab-Approach reveals the high potential of networked learning, working and researching. Democratic sharing in an open-source environment (where open-source is not only related to software developments but as an ideal for community building) will save precious time and money for the people, organizations and institutions involved and increases the value of all the numerous and great developments already made.

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