Networked Experiments and Scientific Resource Sharing in Cooperative Knowledge Spaces

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Abstract

Cooperative knowledge spaces create new potentials for the experimental fields in natural sciences and engineering because 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. The integration of networked virtual laboratories and remote experiments (NanoLab Approach), as well as an approach to community–driven content sharing and content development within virtual knowledge spaces (NanoWiki) are 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 presenting novel collaborative working environments for knowledge acquisition and research as well as supporting natural forms of scientific and technological cooperations.

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 [5]. 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, [1, 11]). Within this approach, social processes, represented by communication, coordination and cooperation, form the basis for successful knowledge acquisition 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.

Experiments play a vital role in natural and engineering sciences, thus their presence in form of virtual and remote laboratories in a cooperative knowledge environment is strongly desirable. We will have a closer look at cooperatively performed experiments in section 3, explaining why they are so essential to ViCToR-Spaces.

2 ViCToR-Spaces – Cooperative working environments for natural sciences

A wide variety of CSCW and CSCL environments has been developed during the last 15 years and many noteworthy results have been achieved. However, the specific

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requirements for cooperative knowledge spaces for mathematics and natural sciences [2] 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-technologies (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 *CURE* platform [4] developed at FernUniversität Hagen serves as the base for ViCToR-Spaces. CURE is an open-source environment designed to build and maintain virtual knowledge spaces. It provides several different mechanisms to support cooperative and communication-oriented work and learning processes. Within CURE, students and teachers meet in virtual knowledge areas to jointly work on shared documents. Room-based access rights management mechanisms such as the concept of "virtual keys" contribute to this open and cooperative way of dealing with learning material. Since CURE permits self-administration, it facilitates the creation of knowledge structures specific to single groups and individuals, thus helping to build virtual communities.

Integration of virtual labs and remote experiments Integrating experimental scenarios and allowing experiments to be conducted cooperatively form one of the most important aspects. These are described in section 3 in detail. Another essential principle of ViCToR-Spaces is the cooperative design, storage and reuse of content and is implemented exemplarily for nanoscience in the NanoWiki approach which will be outlined in section 4.

In the following, we will discuss additional, special requirements for ViCToR-Spaces briefly. These requirements result from the daily practice of students, teachers, researchers and users of mathematics and natural sciences.

Support of special notations 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 or chemical 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 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, wherever possible, be based on common standards such as LaTeX which is well-accepted among mathematicians and users of mathematics, and for which there exists a variety of 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. Geographical distances and various other reasons, however, make this an option which is not always viable.

Shared chalkboards represent an approach to overcome these 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. Lack of rights management may cause content to be changed in a way contradictory to the original creator's ideas, or may allow malevolent users to join a shared chalkboard session and arbitrarily change or even delete objects on the board. 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 also includes a large amount of multimedia objects and interactive components. 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 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 aforementioned field-specific demands, current implementations of virtual knowledge spaces often 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 play an essential role in learning, teaching and research within the technological disciplines and thus form one of the most important parts of the ViCToR-Space concept. To enhance access to experimental setups, there are two principle alternatives [9]: 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 [8, 10]. 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 [12]. 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 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 advertized within the platform whereas other components that might be outdated or (in the case of physical devices) temporarily not available or 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 (sec. 4) 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 adhoc 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 CSCL 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 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, 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-interpretable 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 The NanoWiki approach

To provide background knowledge on the different experiments outlined in the previous section, ViCToR-Spaces also have to contain learning and teaching material and allow access to digital libraries and other scientific resources. As pointed out in section 2, integrating existing eLearning content is one of the core tasks of ViCToR-Spaces. This eContent may derive from a variety of sources, e. g. be "inherited" from previous projects. Due to its highly inter- and multidisciplinary nature, this especially holds true for nanoscience, where knowledge is not only spread among a variety of institutions but furthermore comes from various disciplines such as chemistry, engineering, physics and mathematics. This results in various approaches, scientific ideas and communities which all contribute to the fields of nanosciences or need access to its results. By combining and reusing eContent from these manifold resources, one can design and implement a high-quality course material, interactive self-tests, examinations and, of course, integrate experimental settings and data.

New insights about the roles of new media in learning and education and of collaborative learning styles are making their way into university teaching, impacting academic education [7]. Through their very unique, unconventional and powerful way of web-based collaboration, Wikis [3] have revolutionized traditional notions of cooperation and knowledge exchange. The NanoWiki concept provides novel collaborative authoring environments for knowledge storage and dissemination, accessible through Web Services. In traditional content management systems a restricted author group develops content modules, subsequently releasing them to the user community. In contrast, Wiki environments empower each user to become a contributor ("open editing"), thus already simplifying access to a broad variety of repositories. The Wiki approach does not only help generating new types of content archives – it also induces new user-driven procedures and work sequences as well as new forms of community development.

The central goal of the NanoWiki approach is to provide a basic collection of existing, distributed eContent for nanosciences in order to build a comprehensive knowledge repository. Based on the Wiki concept, NanoWiki realizes an open "lightweight" architecture for community–driven content sharing and content development in nanoscience. Semantic content encoding as well as the extended use of metadata enables intelligent forms of content retrieval and navigational structures adequate for complex, interdisciplinary, fast-growing sciences. New ontologies help to organize the knowledge based on quality criteria and thus provide reusability in different communities or for different applications, such as teaching in high schools, universities, or company training. Thus, NanoWiki will both enrich nano-related eContent and multiply eContent accessibility.

Three main challenges have to be addressed:

- **Content structuring and semantical content enrichment**
  To meet the demands of a self-growing network, innovative knowledge systems need to arrange their content according to field-specific ontologies including semantically well-defined metadata and semantic encoding of the scientific content. These features are not implemented in current Wiki engines, search and retrieval methods are mainly restricted to title and full text search; interconnections between different content objects are invariably realized through simple links. Due to the complexity of the task, only a small number of individuals has been able to participate in the process of ontology building in the past. Recently, the innovative OntoWiki technology has suggested how to incorporate ontology development throughout an entire user community [6].

- **Multicultural and multilingual demands**
  New models of user adaption addressing multilingual and multicultural differences will be designed and implemented within the framework of the NanoWiki project. Beyond traditional concepts of multiple language support, different levels of prior knowledge resulting from different educational systems and professional training models will be supported. Knowledge representation through conceptual graphs and knowledge networks guarantee independency from concepts formed by different natural languages. The integration of community-driven ontology-building supports different approaches and different viewpoints on the same knowledge domain.

- **Quality control**
  The need for quality control in a rapidly growing Wiki environment is the subject of current debate. If intended for educational use, however, quality control is a prerequisite to guarantee scientific excellence and international acceptance. Within NanoWiki a peer-review system will be integrated, ensuring the content quality through a board of internationally recognized internal and external experts. Part of the challenge is the proper balance between quality and speed of content growth.

Three additional issues have to be covered by NanoWiki to apply the Wiki approach to high-quality education and research in the field of nanoscience and nanotechnology:

- **Representing/editing contents in natural sciences**
  Existing Wiki implementations have to be extended by additional features essential for the appropriate presentation of mathematical and natural science related content. This includes the conversion of the de-facto-standard LaTeX into XML/MathML, support of handwriting recognition technologies (specifically adapted to mathematical and chemical formulae), scribble tools to add simple sketches, charts, diagrams and experimental setups as well as connections to virtual laboratories and remote experiments.

- **Knowledge representation and user adaptivity**
  The aforementioned ontological structures form the basis for the realization of non-linear navigation structures, the integration of conceptual graphs and storyboard concepts for individual learning paths and automatically generated knowledge nets, converting traditional content management systems into explorative user-centric knowledge spaces.

- **Usability and interactivity**
  Nanoscale science is an interdisciplinary research effort focusing on nanoscale structures. Collaborative tools for the communication of scientific information including representations of 3D surfaces are of capital importance to support the dialog of the nano community. In traditional Web applications the focus is set on the service and persistence layer, while the usability of the user interface lags behind. With the help of modern web technologies such as AJAX (Asynchronous Java and XML), next generation Wikis can support "desktop-like" usability with more natural browsing experience through "richer" interfaces.

To enhance access to digital sources, NanoWiki will also make extended use of Semantic Web Technologies and Semantic Web Services. Organized by ontologies and semantically described, resources can be integrated across time and communities in a flexible way. Considering the heterogeneous repositories mentioned above, a semantic description of the contents will significantly simplify the handling of contents from these various sources or types.

In order to appropriately present content related to mathematics and natural science, existing Wiki implementations have to be extended by a number of additional features. To deal with the complexity of digital content, ontologies come into place. Thereby, incorporation of ontology development throughout an entire user community (OntoWiki) is an important issue to meet the demands of a self-growing network, in particular in such an emerging and innovative field as nanoscience and nanotechnologies. Specific subject-matter ontologies enable the machine-processable description of the various entities which can be combined to complex units for heterogenous target groups. Furthermore, these ontologies will provide the structure for all new knowledge objects, annotations and changes of all documents that are created. Heterogeneities in the various documents and digital sources are inevitable and will be faced by technical means for ontology mediation. Principled and machine-supported change management of documents will ensure consistency of the documents. Finally, the integration of appropriate composition and navigation tools is an important issue for the presentation of interconnections between the different terms, concepts and algorithms represented by the various knowledge objects.

NanoWiki proposes the next generation in eContent, eContent development and eContent access: based on the open Wiki concept, interactive and semantically enriched building blocks of knowledge will be accessible through innovative Semantic Web and Web Service technologies. A new type of a comprehensive content repository for nanoscience and nanotechnologies will evolve, which is not restricted to eContent storage and retrieval, but will enable students, researchers and developers to contribute and make their knowledge available to a large audience.

5 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 integration and interconnection of independent, single components occupy a central role in providing diverse, comprehensive functionality and addressing a broad, heterogenous 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 acquisition – 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 freelance access to knowledge, we currently face a knowledge landscape of widely spread 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 and NanoWiki approaches 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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