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BeLearning: Using Mental Models to Design Accessible eLearning Applications

Sabina Jeschke
Berlin University of Technology
MuLF-Center, Department of
Mathematics & Natural Sciences
Sekr. MA 7-2, Str. des 17. Juni 136
D-10623 Berlin, Germany
sabina.jeschke@math.tu-berlin.de
Phone: +49 30 31425755
Fax: +49 30 31424413

Helmut Vieritz
Berlin University of Technology
MuLF-Center, Department of
Mathematics & Natural Sciences
Sekr. MA 7-2, Str. des 17. Juni 136
D-10623 Berlin, Germany
vieritz@math.tu-berlin.de
Phone: +49 30 31429941
Fax: +49 30 31424413

Abstract

Flexibility and adaptivity are two of the outstandig characteristics of new media and new technologies in learning, teaching and research. These properties allow new methods to provide physically challenged people with appropriate education. Accessibility of Web applications is typically focused on the perception and control of information. In contrast, the transfer of knowledge as complex information includes further issues of pedagogics and cognitive psychology. Here, the basale role of accessibility for usability and the transfer of knowledge is extended with the concept of mental models to meet the requirements of Web-based teaching and learning. Based on recent approaches for model-based Web application development the BeLearning concept demonstrates the integration of mental models into the design process of accessible eLearning environments.

1. Introduction

Web-based eScience and eLearning platforms offer a great potential to teach physically challenged people. First, the possibilities to distribute teaching materials and communication between all participants have been dramatically improved by computers and the Web. Secondly, based on the separation of content and representation, the same information can be presented through different media types adapted to different sensory perceptions. Finally, in comparison to traditional teaching materials and media forms the modern information and communication technologies include new approaches concerning far-ranging user adaptivity. eLearning platforms can provide the user with additional information about multimedia content, navigation and presentation suited to his own particular needs.

Especially eLearning and eScience technologies offer a wide range of possibilities for pedagogical concepts supporting individual demands and interests. The two deciding factors are given by its interaction capability and the ability to adapt to the user, both practically unachievable using traditional media. These two features are the key to extend the methodology of teaching scenarios as well as the support of individual learning strategies - the integration of new media into the academic education thus possesses the potential to assist in transcending the disadvantages in education of physically challenged people.

Unfortunately, current eLearning platforms are often not accessible to all users. Recent accessibility guidelines for Web applications are often focused on easy access to information and do not address teaching of knowledge. However, the implementation of accessible, highly multimedia-based platforms with dynamic generation of Web pages has to respect the needs of accessibility from the beginning of the design process. Based on semantic content encoding and model-based development, a broad range of accessibility features can be supported. The additional demands of accessible eLearning platforms are discussed in section 2. Especially the concept of mental models is presented in section 2.1 to include issues of teaching and learning.

Part of recent research is Web application development with Model-Driven Architecture (MDA). Web applications are first described in a precise Conceptual Schema (CS) using enhanced UML. Classical MDA-approaches are extended with additional models for user classification, navigation and presentation corresponding to the demands of Web applications. Some approaches even facilitate access to navigation and hyperlinking with additional annotation during the design process. Based on recent proposals for

model-based Web application development a concept is presented in section 3 to demonstrate the possible integration of mental models into the design process of Web applications.

2. Accessibility and Mental Models

Especially in the fields of eLearning platforms accessibility plays a basale role for some further issues like usability and teaching as well as learning of knowledge. Here, accessibility is essential to reach those aims. The WAI (*Web Accessibility Initiative*) formulates some main ideas in the working draft of the to-be WCAG 2.0 (*Web Content Accessibility Guidelines 2.0* [19]): Content and control must be perceivable, understandable and operable by each user and they must be robust enough to work with current and future technologies. In short, accessibility is focused on access to and control of information. Usability and eLearning are based on it. However, they require new approaches to integrate access to information into the propagation of knowledge.

In general, usability is taken as a software quality factor. The standard definition for the usability community is part 11 of the international standard ISO 9241 (*Ergonomic Requirements for Office Work with Visual Display Terminals*) [8]. The definition introduced by Nielsen [14] is the one which is most adopted. There usability refers to learnability, efficiency, memorability, few errors and users' satisfaction [12].

To achieve measurable and precise criteria for a systematical use the principles can be further decomposed and specialized into finer-grained rules. Even for Web use some extra criteria are necessary such as to find desired information, to use direct search and browsing, to comprehend the presented information, invoking and executing specific Web services such as ordering and downloading.

Additionally, eLearning portals are dealing with knowledge which is more than information. Knowledge is the creation of new information based on interpretation and combination of available information. Knowledge includes the way of thinking and represents the highest level in relation to explanatory power. In short, it is complex information. To teach and learn is more than propagating and capturing information and includes concepts of pedagogics and further mental user activities. Here, to realize this distinction between computational data, information and knowledge a hierarchical model (see figure 1) is used.

Three paradigms are possible to realize accessibility for Web applications. All include accessible presentation and control of information as well as accessible generation of content.

1. **Universal Design:** The main idea of universal design is to present all information readable for all users. The recommendations of the W3C are based on the universal design paradigm. For all multimedia content like pictures, graphics, animations etc. a textual pendant must be available. Even the input must be independent from the input device.

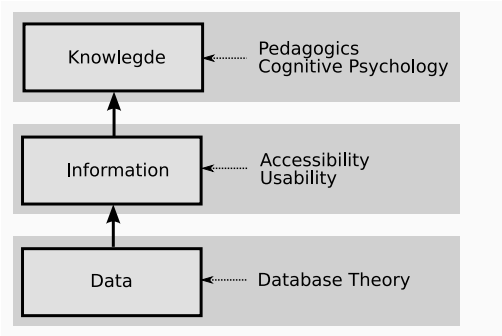

Figure 1. Knowledge – Information – Data

2. **Target-Group-Specific Design:** Dynamic Web applications allow to adapt the presentation to the needs of the user and to support additional information about multimedia content, navigation and presentation. A paradigm based on this is the target-group-specific design that classifies the users in different groups with specific characteristics. For physically challenged people a useful classification is based on functionality (and not on medical diagnosis) such as visually, hearing, physically and mentally impaired people.

3. **User-Centered Design:** Between physically challenged people almost everyone has specific limitations and every classification will be limited. Thus, user-centered means that the user can specify his or her particular needs. A user-centered design involves the user into the presentation, control and generation of information.

2.1 Mental Models

Teaching knowledge includes issues of cognitive psychology and pedagogics. The capability of users to understand ideas and concepts of thinking depends more on their way of thinking than on their capability to receive information with a certain sense. Thus, accessibility of knowledge as complex information comprises a model of their way of thinking too. Accessibility focuses first and foremost on the problems of information transfer. However, knowledge transfer as transfer of complex information cannot be accounted without additional concepts of teaching and thinking. Even accessibility approaches are often hard to combine with other concepts of usability and pedagogics since

they are focused on access to information.

Here, it is proposed to extend flexible design paradigms for accessible eLearning platforms with the concept of mental models to better meet the demands of Web-based learning environments. In cognitive psychology the concept of mental models has been developed within the last two decades. Mental models aim to understand the different kinds of thinking and solving problems. They enable extending the level of information transfer with the level of understanding and imagination. There, the subject of the user and concepts of knowledge as complex information are integrated.

Similarly, a classification of mental models addresses the issue of adaptation in the fields of learning and teaching in a better way. For example the mental models of blind people depend on whether they are blind by birth or later. The association of colors and geometrical notions is as different as that between blind by birth and sighted people.

The basic assumption of mental models are internal models of reality as a vital characteristic of human thinking. They are based on daily experience, learned knowledge and reasoning. The models are constructed for problem solving as mental representation of a given situation. Thereby the available knowledge is used. On the one hand, the mental model is the representation of a part of reality. On the other hand, it is the foundation of thinking and acting. Models are pragmatic since the mapping of original to model is not definite. The choice is affected by the purpose. Thus, mental models are application- or problem-specific.

Mental models are understood as analogical structures that contain the attributes of the original in an interpreted form. The model represents the structure of the original with its own structure and is able to present non-discursive knowledge by similarity.

Mental models are not static. Their generation is the process of qualitative simulation of the outside world within the continuous course of which they will be developed. Thus, cognitive psychology distinguishes different states of models. Perception models are formed by perception and are the basis of further cognition. Conceptual, causal or cogitative models can simulate higher complexity.

Different approaches are proposed to classify mental models. Here, the taxonomy of Hartmann and Eberleh [7] is mentioned which is based on the work of Johnson-Laird [9]. It separates physical from conceptual mental models. Physical models represent aspects of the real world and conceptual models represent aspects of the symbolic-linguistical world. Furthermore, physical mental models can be separated into models with a chronological structure and models with a spatial structure. Based on Lewins concept of "topology" spatial models can be topological or metric. Conceptual models are putting knowledge into relation with linguistic notation. They have a relational structure and differ one from another in relation to their power in meta-linguistic and hierarchical models.

Lorscheider [10] classifies mental models on their level of organization. There are individual and collective models. A useful classification and specification of mental models for accessible learning environments is part of future work.

2.2 Summary: Demands of Accessible Dynamic Web Applications

As already discussed the target-group-specific design and the user-centered design are flexible to adapt the presentation to user needs. Together with appropriate mental models profiles for presentation, navigation and control of the Web application are possible which combine aspects of perception and interaction with aspects of thinking.

However, the development of flexible, accessible eLearning applications with dynamic Web page generation requires a semantic encoding of the complete content to realize the separation of content and presentation. Supporting the underlying semantic technology is vital to realize a broad accessibility of highly interactive virtual knowledge spaces and incorporating intelligent tools for the development and administration of content. Here it is important to mention that semantic encoding may not be restricted to the content elements themselves, but has to include all aspects which are highly content-related as, for example, navigation mechanisms and interactivity. Even the storing of semantic data in XML-dialects has to respect some issues to support a semantic-rich XML-language and documentation as well as export of the semantics.

Here, model-based development is proposed to facilitate the design of complex, accessible Web applications. Model-driven development is related to a design process where all information is available to provide the designed application with the semantic information about the used objects, their relations and meanings. Storing this knowledge in a way enabling the compiler to automatically generate all required information, model driven design processes for Web applications are a promising approach for bringing together the requirements of learning environments and accessibility. Thus, conceptual design can enable accessibility without extra effort.

3 Conceptual Design

Nowadays it is more than ever accepted that the development of quality and reliable software applications has to start with a precise description of an information system in a model. This model can be described with a sound and unambiguous Conceptual Schema (CS) using the wide extension of the Model Driven Architectures (MDA). The CS

includes static aspects, dynamic aspects, structure and behavior. Afterwards a model compiler transforms the CS into its corresponding application with defined mappings between the conceptual primitives and their software representations. The implementation of model compilers was driven by the development of such mappings.

Model-based Web application development is based on the principles of MDA for an object-oriented approach. The design process is controlled with use case scenarios, architecture-centered and uses iterative as well as incremental steps for development. Thus, it is appropriate for complex Web applications which are complex in respect to content, structure, function and technology.

The design of a CS is, applied to Web applications, an even bigger challenge additionally complicated by some missing features of UML to model Web-based applications. Not only is it necessary to map the structure and behavior of the whole application but also that of the intended navigation and presentation. Therefore, a challenge of research on conceptual modeling is currently the design process of Web applications. Some already existing interesting proposals are WebML [18], Web Site Design Method (WSDM [4]), Object-Oriented Hypermedia Design Method (OOHDM [6]) and Object-Oriented Web Solutions (OOWS [16]). Here, OOWS is presented as an example since it extends an object-oriented design approach and seems suitable for the design of complex server-based Web applications and the BeLearning concept (see section 3.3) uses this approach for further extension. Furthermore, the Dante approach is described which aims to improve accessibility for visually impaired people.

3.1 The OOWS Approach

OOWS extends the object-oriented software development approach OO-Method [15] with additional capabilities to capture the navigational and presentational requirements of Web applications. Navigational and presentational designs are integrated to object-oriented conceptual modeling and systematic code generation is provided.

The OO-Method was extended with three additional models: user, navigation and presentation model. OOWS defines a set of activities to properly specify the functional, presentational and navigational aspects (see figure 2). A fully operative Web model compiler that includes the presentational layer is part of future work.

The extension of "classical" conceptual modeling starts with the user diagram to determine the kind of users which can interact with the application and what visibility they have. The diagram supports user specialization and user taxonomies for specification reuse. Three types of users exist: anonymous users, registered users and generic users.

Then, for each user type a system view must be specified. A global view and a detailed view describe navigation specifications with a class diagram. Class attributes, relationships and operations are used to determine visibility for each user.

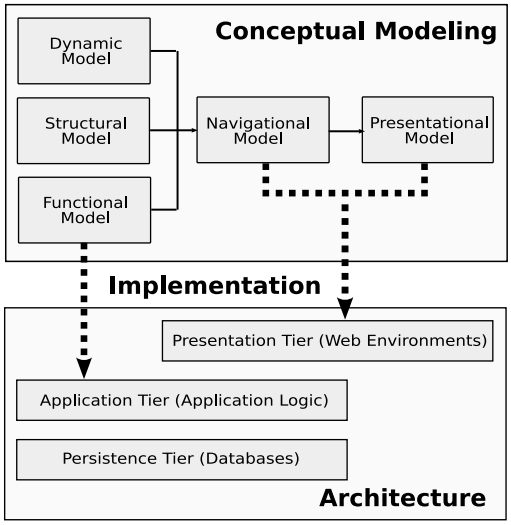

Figure 2. Overview OOWS Approach [2]

The presentational model ist based on the navigational model. It uses patterns to associate the primitives of navigational context like navigational links or searching mechanisms with presentation properties.

An additional approach [5] is combined with the navigational model to include the description of adaptive navigation techniques in the early process of Web modeling. Even if this technique is not intended to improve accessibility it can be extended to support orientation for visually impaired users since they use links to gain a quick outline of a Web page. Three techniques of linking are included: link-annotation, link-hiding and link-ordering.

3.2 The Dante Approach

The Dante project [1] aims to improve the access for visually impaired people to Hypermedia environments – especially the Web. It is focused on devising a tool to analyse and transform Web pages using a model-driven approach and generating annotations from the design specifications.

Usually, visually impaired users have to rely on screen readers. In some countries Braille devices are often used, having the same impact on this discussion. This assistive technology read the content sequentially and cannot detect and present the meaning of different page objects. Without further information this implicit knowledge of the structure is not accessible to visually impaired people. Extra semantical annotation can avoid the problem if the screen reader is provided with additional semantic information.

The Dante-approach allows semantic annotation of Web pages to explicitly provide knowledge about structure and to support screen readers to facilitate the audio presentation of the content. The identified objects are annotated with terms from the Web Authoring for Accessibility ontology (WAfA). Currently, such annotations were done manually and do not address the problem of dynamic content.

In combination with the Web site design method WSDM it is possible to fully automate the generation of semantical annotations used for Dante [17]. It is estimated that 85% of the annotations can be provided in this way. This makes Dante interesting for dynamically generated content.

3.3 The BeLearning Approach

Within BeLearning at the Berlin University of Technology, model-based development of accessible Web applications is investigated. Thereby, Moodle [2] (as a non field specific eLearning platform) and Mumie [3] (as a field specific platform for mathematics) serve as demonstration environments.

Supplementary annotation of images is investigated to support accessibility to multimedia content. The field of navigation is one of the major issues to support accessibility. Another one is multimedia content. Starting from both presented approaches to improve navigation techniques BeLearning examines the possibilities to extend the accessibility features for multimedia content too. Images, graphics etc. have different functions in Web content. They can serve for decoration, representation, interpretation etc. Current discussions concerning presentation are usually focused on the meaning to be conveyed by the objects as the description of a visual object is meaningless to visually impaired people if it is not related to concepts available to their imagination. Otherwise it is important to communicate the significance of the picture so that the user can understand why the image is there and if it is necessary to recognize all details.

Even if a lot of these aspects can be carried by text too or it is not necessary to understand the content a complete substitution is not possible. If the Web application model declares the function of an image it can be decided which substitution can be applied. To make this kind of content accessible at first function and intention must be clear for the user. This sort of ”semantic information” is available from the Web model too and can be processed by the model compiler. Another interesting approach to translate images into haptical graphics presents Kurze in [13].

Based on the OOWS and OOHDM a concept (see figure 3) is presented to explicitly address the main fields of accessibility – perception and interaction – and to meet the demands of complex server-based Web applications like eLearning environments. Therefore it is necessary to design representation and interfaces too. In the representation model images are combined with objects from earlier models like the functional model and the navigational model which declare the function represented by the image. In most of the cases alternatives are possible. The development of the user model and the conceptual design of the application as well as interface design and navigation design are parallel operations affecting each other.

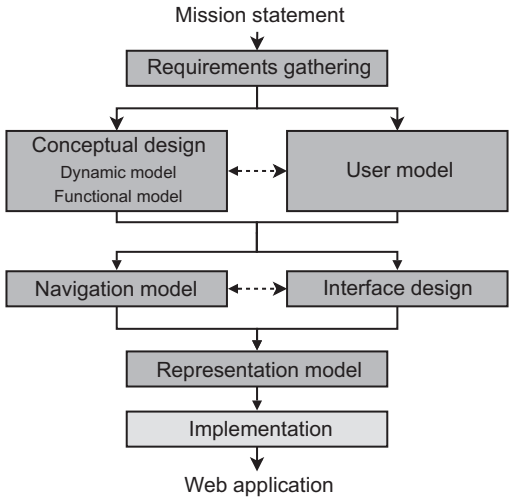

Figure 3. Overview BeLearning Approach

Mental models are integrated at first within the user model and later used to specify presentation, navigation and interface requirements within the appropiate models. As an example figure 4 is shown where “abstract model” and “geometrical model” represent two different user types which imagine mathematics with abtract or geometrical mental models. A detailed user model including a classification of mental models is part of future work.

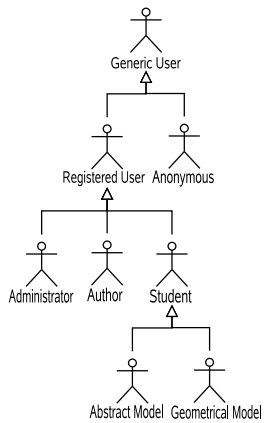

Figure 4. Example for BeLearning User Model

4 Conclusion and Outlook

The concept of mental models offers advantages for the development of accessible eLearning platforms. The specific requirements of learning scenarios can be integrated into the design process of complex Web applications. The use of mental models enables to overcome the absence of user subject in "classical" information theory and to integrate the mental user activities. Mental models are a appropriate concept to integrate the more of knowledge as complex information.

With the presented approaches model-driven Web development can support accessibility in the fields of navigation and illustration. This is not a general approach to support accessibility in all aspects since the support of interaction is not discussed and also multimedia includes not only images. However, the basic idea is applicable to other fields too: Accessibility at first is not a question of a simple replacement with other media but to extract the function and purpose of information and find ways to describe these information with models understandable for model compilers. Even if interactions with the user are not discussed here in detail they are affected by the issues of perception too. Often the problems of interaction are at first not problems of input but orientation, explanation etc. Within Belearning is subject of further examination:

- a detailed concept of mental models for use with user models to support the model-based development of accessible Web applications
- a prototypical implementation to evaluate the possibilities of mental models in model-based Web design
- to examine how mental models can be used with existing eLeaning platforms as Moodle and Mumie to improve the support of teaching and learning
- the integration of interactions in the model-based Web application development process

More issues for future work are other kinds of multimedia content like applets, the use of SVG (Scalar Vector Graphics) to enhance accessibility etc.

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