

The first AdeLE Prototype at a Glance

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Abstract: According to literature, a lot of research work on adaptive e-learning was carried out and, insofar, many systems in this application domain were developed in the last decades. One solution approach within the scope of adaptive educational hypermedia is the project AdeLE (Adsaptive e-Learning with Eye-Tracking), started at the end of the year 2003 and with the scientific focus on combining adaptive e-learning techniques with eye-tracking technology. After two years of research and development we present the current status of the adaptive e-learning environment realised so far. Thus, this paper sums up relevant publications concerning the AdeLE system, highlights the overall prototype as well as each subsystem and points out our experiences gained within the first phase of the project.

1 Introduction

Adaptive e-learning, as stated e.g. in (Shute & Towle, 2003), comprises a research and development stream dealing with educational systems that adapt the learning content as well as the user interface with respect to pedagogical and didactical aspects. Although adaptive e-learning, adaptive educational hypermedia and the forth are often considered to represent modern and innovative solutions, basic theoretical approaches can be tracked back to the 1920's and first systems implementing these concepts are dated back to the 1960's (see for example Park & Lee, 2003). As summarised in (Brusilovsky, 2004), a lot of researchers started to work within the area of micro-adaptive instructional systems in the last 15 years and, thus, several technological prototypes and solutions arose. From the theoretical point of view, the research project AdeLE is an attempt to implement an adaptive e-learning environment that applies different theoretical approaches in a single system (see section 2).

The AdeLE project was started in the year 2003, and its name stands for 'Adaptive e-Learning with Eye-Tracking'. From the practical viewpoint, AdeLE comprises a technology-based solution in the field of adaptive e-learning exploiting novel methods of resolution for fine-grained user profiling based on real-time eye-tracking and content-tracking information (see AdeLE, 2005). One of the project's main aims is to evaluate the usability of eye-tracking techniques in terms of scanning-paths, i.e. we are trying to detect (a) if some patterns are identifiable and usable for differentiating among 'reading, learning and searching' activities, and (b) behavioural parameters such as 'observing a picture', 'reading a text' and 'looking on navigational elements'. Because the evaluation of these parameters is not concluded yet, this paper focuses on the server-side functionality of the system, which is called the *first AdeLE prototype* and, for the first time, described as a whole including all subsystems.

The following section gives an overview over the development process of the overall system. In section 3 we outline theoretical aspects and the realisation of the prototype's subsystems. Section 4 depicts our experiences with respect to software development and to the system's applicability including aspects of combining adaptive educational hypermedia and eye-tracking technology.

2 Related Work about the AdeLE Prototype

Several publications describe the progress of our research work as well as the development process of the AdeLE system. For example, (Gütl et al., 2005) reported about the overall idea of the research project, our goals and abstract scenarios. In (Mödritscher et al., 2004a) we described our theoretical model for adaptive e-learning based on well-known mainstreams and system types. (Gütl et al., 2004) dealt with the architectural design of our prototype and concrete requirements on the adaptive e-learning environment. In (Mödritscher et al., 2004b) we identified the need to provide standardised learning content and suggested the standards and specifications of SCORM slightly modified to fit our requirements.

Further, the applicability of a Dynamic Background Library (DBL) within the scope of adaptive e-learning is examined in (Mödritscher et al., 2005). (Gütl & García-Barrios, 2005) outlined implementation details of the Modelling System of AdeLE. In (Gütl & Mödritscher, 2005) the technical realisation of AdeLE's Adaptive System

is summarised. Finally, (Safran et al., 2006) described the implementation of a Concept-based Context Modelling System (CO2), which represents an enhanced multi-purpose version of the first prototype of the DBL. This short overview about some of our milestones shows the development line towards a first running prototype, which in essence consists of different interacting systems with distinct purpose-specific functions. At the current stage we do have a running prototype, which is presented from the architectural and functional viewpoint as a whole in the following section.

3 The first AdeLE Prototype and its Subsystems

Summing up the basic idea behind the AdeLE research project, we focussed on two important issues while designing the architecture of the overall system (see figure 1). Firstly, it was clear that the client has to collect continuously a large amount of data due to the application of the eye-tracking device. Thus, we placed the ‘sensory systems’ (Eye-Tracking System and Content-Tracking System) to the client-side with the intention of reducing the information and communication load of the server-sided system. The learner’s interaction with the e-learning environment is tracked by the Learning Management System (LMS) ‘as usual’. Secondly, it was required to design the system as a set of subsystems consisting of reusable services.

Following well-known procedures, as recommended e.g. by (Shute & Towle, 2003) or (Conlan, 2005), we extended a typical LMS, and its Web client, by typical elements for adaptive and personalised e-learning. Thus, we reused and adapted an open source LMS solution, and implemented then the following subsystems on basis of a service-based approach: (a) the Adaptive System to personalise the learning process, (b) the Modelling System to manage learner profiles and necessary models, (c) the Concept-based Context Modelling System (CO2) to model the conceptual space of courses, and (d) the Background Knowledge Repository to provide context-dependent background knowledge.

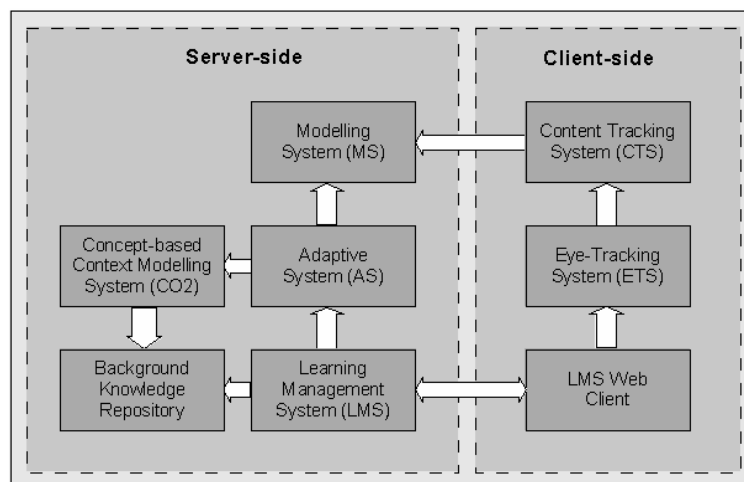


Figure 1: Overview over AdeLE's architectural Design

In fact, the architectural design of the system forced us to look for a framework to implement the first AdeLE prototype with respect to important aspects of software engineering and system operation, such as flexibility, extensibility, modularity, connectivity, reusability and performance. After evaluating various technologies and products like the J2EE-based JBoss Application Server, Microsoft .NET, the OSGi Service Platform, and others, we decided to utilise the Openwings framework (see General Dynamics C4 Systems, 2005), which is rather unknown, but offers mighty possibilities for the realisation of distributed service-oriented systems. Some functional and implementation-related details about the subsystems of the first AdeLE prototype show the following subsections.

3.1 Learning Management System

One of the first issues to decide within the AdeLE project addressed the question, if an own and full-featured LMS should be implemented or not. Considering the most important features for an LMS (see e.g. Dietinger, 2003)

as well as state-of-the-art standardisation efforts, we decided to utilise ADL's SCORM Runtime Environment (see ADL, 2005) as front-end for the system. Nevertheless, the following modifications and extensions had to be made:

- Due to the restrictive dependence of the database to the Windows operating system, we applied the Torque database layer using a MySQL database for this application. Thus, it is possible now to develop and provide the AdeLE prototype under the operating system Linux.
- Further, we had to integrate the chosen LMS into the Tomcat service of Openwings.
- Finally, it was necessary to add some AdeLE specific packages and to modify some source files, so that the Adaptive System can take adaptive control of the whole learning process. In most cases, these modifications of the existing LMS are rather negligible and do not have severe effects on the overall behaviour of the system. Such changes comprise the notification of the Adaptive System on each user interaction as well as smaller extensions of the tree-view navigation. Yet, ADL's 'sequencing engine' responsible for visualising the instructions was re-implemented to fulfil our requirements.

Figure 2 shows a screenshot of the LMS's front-end presenting the learner an exemplary course. While the layout is similar to ADL's SCORM Sample Runtime Environment, the navigation frame includes some minor changes like an improved visualisation of the tree-view and new features such as (a) automatically generated additional concepts for the current instruction (i.e. provision of context-dependent background knowledge generated by the CO2), (b) alternatives to the adaptive decision about the current instruction (i.e. provision of understandable and controlled adaptation), and (c) information about the learner model (i.e. provision scrutability of user models).

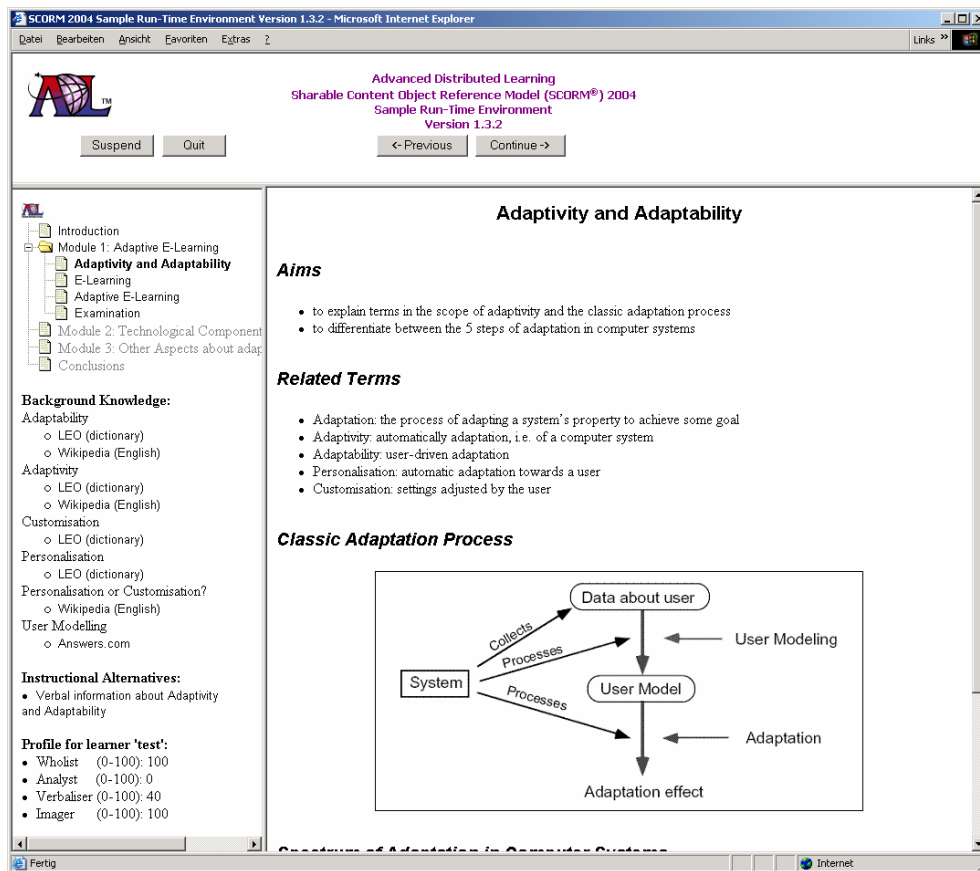


Figure 2: Learner portal with slightly modified tree-view navigation and extended by the areas Background Knowledge, Instructional Alternatives, and Profile

As can be concluded so far and should be stated at this point, our solution approach reaches a high degree of flexibility because of the fact that we consider the applicability of e-learning as a flexible and support of purpose-based *tools*, which in turn should fulfil concrete didactical requirements. Thus, we implemented a full-featured,

standard-conform and web-based LMS extended with the possibility that the adaptive e-learning environment and/or the user adapts the learning process as shown in the following subsection.

3.2 Adaptive System

Generally speaking, the Adaptive System aims at adapting the learning process. Therefore, we built up a theoretical model of adaptation comprising the important idea that the adaptation carried out by the system can be understood, influenced and also completely driven by the learner. In concordance with (Shute & Towle, 2003), we applied different models for the adaptation methods: (1) the content model and the instructional model is given by SCORM's manifest file, which is sent by the LMS after the first visit of a course; (2) the learner model is provided and managed by the Modelling System (described in the next section); (3) the knowledge structure of a course can be modelled with the CO2 (see subsection 3.4), which supports an extended learner tracking and the idea of concept-based learning; and (4) the adaptation model is implemented within the Adaptive System (see figure 3).

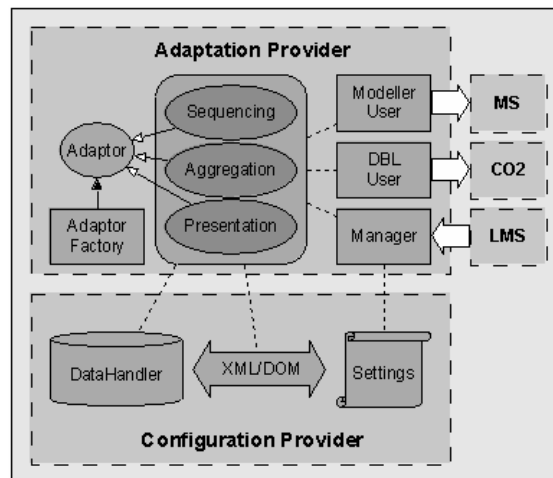


Figure 3: Implementation details of the Adaptive System

The adaptation process itself considers three important techniques (see Adaptation Provider in figure 3) explained as follows. Firstly, adaptive 'Sequencing' of instructions comprises the idea of adapting the path through the course on basis of learner observation and didactical rules. Secondly, adaptive Aggregation deals with selecting and sampling resources to an instructional unit. Thirdly, adaptive Presentation describes the visualisation of the instructions as well as navigational elements. From the software development viewpoint these three techniques are realised by so-called Adaptors, which are implemented (so far) following a simple Product Factory design pattern. Yet, we are aware of the fact that it would be better to apply an Abstract Factory to handle a product family of adaptors, e.g. for a different e-learning standard or platform. From the viewpoint of cognition sciences, the information for the adaptation is still restricted to the WAVI model (see Riding, 1991). Nevertheless, it is planned to build up and use a more flexible learner model for determining the indicators to adapt the learning process.

3.3 Modelling System

The task of this subsystem is to provide and manage the user profiles as well as learner models used to adapt the learning process. According to (Gütl & García-Barrios, 2005), four components were identified, and each one was implemented as an Openwings service (see also figure 4 in the next subsection):

- The Manager is responsible for communicating with external systems such as a profiler editor, the eye-tracking system, other sensory systems, an adaptive engine or even external knowledge management components. It can be seen as single and central dispatcher of the Modelling System.
- The Profiler deals with all necessary operations concerning the management of learner profiles. In essence, a user profile consists of purpose-oriented sets of simple user attributes (e.g. static user traits, interaction sequences, logging data, etc.), which might be accessed by other internal modules in order to enrich its semantic value (e.g. an inference-based user model or a standard-mapping service).

- The Modeller realises various user modelling services, which are considered as high-semantic information extractors above the raw-data user profiles, e.g. the WAVI modeller or a dynamic (real-time) state modeller of the learner. Thus, it is easy to add new modellers or move other models like the course or adaptation model to this service of the Modelling System.
- The Data Handler provides different tools for data management (i.e. access to persistent user data).

At present, the first AdeLE prototype is able to handle with the WAVI model as well as to track dynamic real-time user state models. Presently, only the WAVI factors are used to adapt the learning process. Nevertheless, we might also be in need of the state modeller due to the observation of the learning behaviour through the eye-tracking device. To illustrate the use of the state modeller, consider the example where some learning objects (e.g. textual passages or images) are marked as ‘to be looked at’ or ‘to be learned’ and the eye-tracking device may distinguish between these ‘states’; thus, if a text passage was only read and not learned, the state modeller monitors this discrepancy and makes it available to the Adaptive System, which in turn may react in a correspondent manner.

In concordance with other modern research movements, we have considered the following critical issues for the Modelling System. Regarding scrutability and openness, the user model needs to be transparent as well as controllable by the learner or by external applications. Mentioning access by external system, it is also necessary to implement privacy aspects such as access control, e.g. by pre-defined roles and authentication. Further, we are working on the realisation of proactive behaviour, so that the Modelling System might ‘autonomously’ force certain interactions in order to initialise or actualise a user model. Last but not least, we have implemented a GUI-based tool to view and edit the user profiles and models of AdeLE.

3.4 Concept-based Context Modelling System and Background Knowledge Repository

The Concept-based Context Modelling System (CO2) described in (Safran et al., 2006) has two important tasks for our solution approach. First, as an enhanced version of the Dynamic Background Library (DBL), this subsystem allows the modelling of the knowledge domain of a course by means of concept definitions through a contextual space. These concepts can be assigned to the instructions of the course and provide references to various repositories containing the background knowledge. On the other side, the CO2 represents a powerful additional tool, which (a) supports context-based adaptation of learning processes (i.e. thematic-driven learning as introduced in Dreher et al., 2004), (b) extends the advantages of navigational elements based on the conceptual model of the course, or (c) enhances learning progress tracking by connecting the concepts with the learners’ achievements.

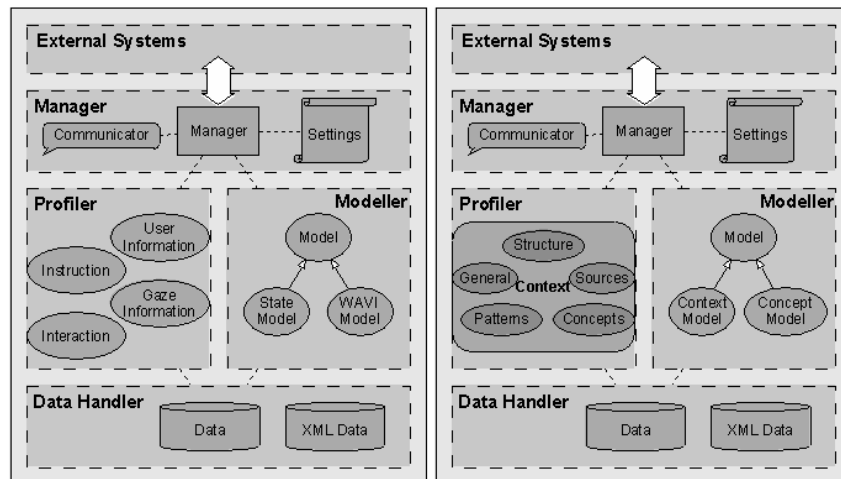


Figure 4: Service-oriented Architecture of AdeLE’s Modelling System (left side) and Concept-based Context Modelling System (right side)

The architectural design of this subsystem (see figure 4 below) is similar to the Modelling System. Yet, the tasks of the CO2 and the resulting implementation are distinct in certain areas. In the CO2, the Profiler processes information about the context, i.e. a hierarchy of context items, the concepts within this context and the matching patterns (synonyms). The Modeller aims to provide the models for a context retrieved from the profiler and

containing information on a higher semantic level (i.e. the current implemented models interpret the meaning of conceptual spaces for its utilisation within the field of e-learning). The Manager and the Data Handler of the CO2 work in the same way as the corresponding services of the Modelling System.

Within the first AdeLE prototype it is possible to define and manage concepts for a course using a GUI-based tool. Therefore, a teacher can create a knowledge domain by defining one context-item for each instruction (even for exams), determining various information retrieval systems providing course-relevant background knowledge and connect these concepts with any context-item. Presently, the context-dependent concepts are visualised in the LMS as shown in figure 2 (see section Background Knowledge in navigational frame on the left side). Thus, the CO2 represents a didactical tool for teachers to structure their courses and manage their static background literature as well as another dynamic information sources for enhancing or adapting the learning process, e.g. by improved learning progress tracking, context-driven adaptation, support of thematic-driven learning, and the forth.

The Background Knowledge Repository comprises all information retrieval systems (IRS) addressed by the CO2. As arbitrary IRS's can be defined as knowledge sources for the concepts, it is possible to access directly an internal IRS or even an external one by implementing its query definitions or API. For example, a teacher could use Wikipedia to provide the definition of a concept, Google Images to retrieve concept-related pictures and online dictionary services to offer translations. The currently IRS integrated into the first AdeLE prototype is the xFIND system, a smart knowledge discovery system developed at IICM (see Gütl, 2002).

3.5 Eye-Tracking and Content-Tracking System

These two subsystems located at the client-side of the AdeLE prototype implement two relevant issues within the AdeLE project. On the one side, the Eye-Tracking System records the learner's eye movements. On the other side, the Content Tracking System tries to derive implications of the user's gaze for the learning process by connecting the gaze scanning paths with the content and updating the learner models within the Modelling System. By following this approach, the server hosting the LMS is not loaded by these analysis tasks, which require a lot of resources to process the large amount of processing data. At this moment, the Eye-Tracking System is realised with the software packages supplied by the eye-tracking device, while the Content-Tracking System is not implemented yet due to ongoing studies trying to detect significant gaze patterns. Nevertheless, the Modelling System already provides an interface to update user models with respect to the indicators inferred by the eye-tracking device.

4 Experiences so far

After two years of research and development, the first AdeLE prototype is finished and an online demo demonstrating the current version of the prototype is available under (IICM, 2005). In this section we report about our experiences with this prototype. In general, we want to highlight the system from two points of view, the technological design process (software development) and the applicability of the prototype (scenarios).

4.1 Software Development

Within this research project, we faced two important issues concerning the software development process of the AdeLE prototype.

On the one side, we did not want to reinvent the wheel and invest a lot of time to realise a distributed system on basis of low-level concepts, such as connecting subsystems via sockets or sending proprietary http-requests. Thus, we decided to implement the prototype by means of high-level programming and to apply a service-oriented architecture, which led to the selection of the Openwings framework. In general, the Openwings reference implementation allows to develop and to provide services without dealing with the low-level programming issues mentioned above. The subsystems introduced in section 3 (except the Eye- and Content-Tracking System) consist of at least one Openwings service. Technically speaking, the realisation of an Openwings service is very easy: firstly, as Openwings is a Java-based framework, it is possible to directly apply the object-oriented programming paradigm, and secondly, design patterns are effectively applicable without taking special care of typical problems of distributed systems, such as the problematic aspects of the Singleton pattern stated in (Pant & Ondo, 2002). In addition, Openwings supports a lot of important concepts of software development, e.g. platform independency, scalability, flexibility, modularity, and so forth. Yet, it has to be said that it is important to create and handle the services' policy files very carefully, because errors within a policy may cause strange side-effects and can be found very hard.

On the other side, we evaluated different development strategies for the single subsystems. At the beginning, the Adaptive System was implemented as one large service (Adaptation Provider in figure 3). Later on, we added

another service for generally usable tools such as an XML-DOM converter, a data-handler, a settings module, and the forth. In order to evaluate how much services a subsystem should contain, we carried out a case study and implemented two versions of the Modelling System: (a) the first one consisted of five services – the four services pointed out in subsection 3.3 as well as one service for the GUI-based administration tool –, which we called the ‘macro-service approach’; (b) the second version of this subsystem, which we named ‘micro-service approach’, consisted of 16 services (see Gütl & García-Barrios, 2005). As a result, we came to the conclusion that implementing too many services is time-consuming and causes too much network traffic as well as a high degree of complexity. In contrary, using too few services has negative effects on the flexibility and re-usability of code. A specific or efficient number of services could not be identified, because it depends on the requirements for the system in terms of functions and communication interfaces.

As can be concluded from this subsection, we recommend the use of a service-based approach to realise an adaptive e-learning environment.

4.2 Application Scenarios

Regarding the experiences described in (Gütl et al., 2005), the following scenarios about our server-sided AdeLE prototype and its relevance for eye-tracking can be pointed out.

The scenario ‘individual learning strategies’ is already fully realised with our current solution. Although the data input of the eye-tracking device is still missing, the prototype provides personalisation of the learning process, where the adaptation can be triggered by the user interaction through the LMS as well as by sensory systems such as an eye-tracking device. Personalisation issues are currently implemented in a rather simple way using the WAVI model, where navigational elements are adapted with respect to the wholist-analyst-factor, while the instructions are selected according to the verbaliser-imager-factor. Other learner observation and personalisation strategies would be easy to implement due to a high degree of flexibility through the Modelling System, which is able to manage user states and can be extended by other user models, as well as through the Adaptive System, which is able to implement several sets of so-called Adaptors. We plan to develop an improved adaptive engine enabling a comfortable customisation of different adaptation strategies.

The scenario ‘additional context-specific information’ is restricted currently to the utilisation of the CO2, which offers a context-dependent visual representation of dynamic background knowledge. Yet, we are not able to highlight relevant spots within images without the eye-tracking device. Furthermore, this feature is hard to implement within the actual prototype, because it would be necessary to describe the connections between text and images via meta-data and we would need some tools to manipulate the images of the learning content.

The scenario ‘appropriate intervention strategies’ comprises the idea of intelligent tutoring systems, which is already provided by the overall functions of the first AdeLE prototype. Yet, some requirements concerning improved learner observation applying the eye-tracking device are not realisable presently.

Finally, it has to be mentioned that the other application areas are not supported by our first prototype. A more detailed progress tracking could be achieved by applying the DBL and evaluating the learner’s competencies about a course conceptual space. In addition, we still have not evaluated our model of adapting the learning process.

5 Conclusions and Outlook

The current version of the AdeLE prototype provides all typical features of an LMS, which allows the learning through a course similar to any other standard conform e-learning platform. Importing a SCORM-based course that supports the possibilities of the AdeLE system enhances the learning process by enabling the adaptation model we have realised within this prototype.

From the viewpoint of software development, we recommend the use of Openwings due to different issues. The service-oriented architecture of the Openwings reference implementation supports our understanding of e-learning as a tool repository and allows the integration of further tools very easily. Furthermore, concepts such as flexibility or scalability can be realised very fast, e.g. by developing new services or relocating heavily loaded services onto other Openwings platforms. Finally, software development within Openwings disburdens some critical aspects of distributed systems such as the ‘multi-threaded singleton’, due to an encapsulation of a Java Virtual Machine within one service.

All in all, we believe (and hope) that we developed so far a solid basement for our ongoing research activities in the first half of the research project. For future work it is planned to develop a more flexible version of the Adaptive System in order to customise the rules for the adaptation in a more comfortable manner. Further, a more powerful CO2 is planned, which should enable the management of semantically interrelated concepts. Finally, we

also have to evaluate some of our implemented ideas, e.g. the pragmatic value of the use of the DBL (and CO2) for different learning activities, the acceptance of real-time adaptational procedures by means of an intrusive sensor (eye-tracker), or the usability of Modelling and Adaptive System.

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