AdeLE (Adaptive e-Learning with Eye-Tracking): Theoretical Background, System Architecture and Application Scenarios

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Abstract

Due to the rapidly growing amount of knowledge, a stronger need emerges for efficient and improved knowledge acquisition strategies. E-learning can be very helpful for different learning activities in various learning environments. However, in order to support different teaching and learning paradigms, e-learning should deal with more than simply reading online lessons. Therefore, content as well as communication and collaboration have to be supported in a highly personalised manner by e-learning systems. Though, tracking and grasping the user behaviour in real time remains the most challenging task to retrieve an appropriate and fine-grained user profile as well as to provide personalised learning content. In this paper we present AdeLE, a technology-based solution of an enhanced adaptive e-learning framework, which comprises novel solution approaches for fine-grained user profiles by exploiting real time eye-tracking and content-tracking analysis as well as a dynamic background library. Based on the global objectives of an enhanced e-learning environment, the system architecture of AdeLE and the methods used in order to gain fine-grained user information by real time eye-tracking are addressed. Furthermore, various scenarios in different application domains are illustrated.

Der rasch ansteigende Umfang an Wissen bedingt einen zunehmenden Bedarf an effizienten und verbesserten Strategien von Wissenserwerb. E-Learning kann für unterschiedliche Lernaktivitäten in verschiedenen Lernumgebungen sehr hilfreich sein. Um jedoch verschiedene Lehr- und Lernmethoden zu unterstützen, muss E-Learning mehr als nur simples Lesen von Online-Lektionen bieten. Deshalb sollten E-Learning-Systeme Inhalte als auch Kommunikations- und Kollaborationsaktivitäten in stark personalisierter Weise unterstützten. Um ein geeignetes und feingranulares Benutzerprofil zu erhalten und um personalisierte Lerninhalte zur Verfügung zu stellen ist jedoch das Verfolgen und Erfassen vom Benutzerverhalten in Echtzeit eine große Herausforderung. In dieser Arbeit präsentieren wir AdeLE, eine Technologie-basierte Lösung eines verbesserten adaptiven E-Learning Frameworks, welches einen neuartigen Lösungsansatz für ein feingranulares Benutzerprofil durch Nutzung von Real-Time Eye-Tracking und Inhalts-Tracking Analysen sowie die Anwendung der dynamischen Hintergrundbibliothek umfasst. Aufbauend auf den allgemeinen Zielen der verbesserten E-Learning Umgebung werden die AdeLE Systemarchitektur und die Methoden zur Gewinnung von feingranularen Benutzerinformationen mittels Real-Time Eye-Tracking adressiert. Weiters werden verschieden Anwendungsszenarien in unterschiedlichen Bereichen erläuternd dargestellt.

Keywords

e-learning, adaptive knowledge transfer, dynamic background library, user profiling, eye tracking, AdeLE

1. Introduction

It is well documented in renowned research publications and studies that the increasing amount of knowledge and therefore the serious demands on knowledge acquisition for students and employees requires improved and efficient learning activities. Furthermore, people have to be supported and assisted during their life-long learning activities. Traditional learning methods and environments do not meet the contemporary needs of our information society any more. Thus, technology-based solutions have been increasingly established to overcome these problems. As a result, e-learning can be identified as one of the emerging areas in the last few years, as shown by means of concrete numbers in the (IDC 2003) study. About 934 Mio US$ were invested in e-learning worldwide in the year 2003 and the European market is meant to be the best one. Though, a lot of failures and only a few - in most cases locally restricted - success stories can be identified (see also Baumgartner 2003).

In this paper, we introduce our new solution approach, named AdeLE, which is the abbreviation for 'Adaptive e-Learning with Eye- Tracking' and 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. By applying fine-grained user profiles and real-time behavioural data about users, a highly personalised information provision and a wide range of new applications are facilitated. Given that the objectives of technology-based educational environments and their impact on individuals are linked with complex and context-dependent constraints and conditions, we are conscious that the solution framework presented in this paper may only be valid for specific sub-fields of e-learning.

In concrete, this paper represents an extended version of 'AdeLE: A Framework for Adaptive E-Learning through Eye Tracking', presented at the IKNOW 04 (see García-Barrios et al. 2004), whereupon the scope of this version is extended by and focused onto a practical discussion of real-time eye-tracking and a description of practical application domains. Thus, the reminder of the paper is organised as follows: Section *2. Motivation*, describes key issues and requirements for the proposed system, in Section *3. Related Work*, a selection of related research topics is depicted, Section *4. Real-time Eye-tracking,* discusses specific features of eye-tracking technology and the application of its real-time application for the AdeLE framework, Section *5. Architectural Overview of the AdeLE Framework*, provides a technical insight into the modules of the AdeLE architecture, and in Section *6. Application Scenarios*, examples of application areas for our solution approach are discussed.

2. Motivation

Our previous experiences in the subject of e-learning (e.g. Dietinger 2003; García-Barrios et al. 2001; Pivec

2000) have shown that learners tend to stick to distinct learning methods and teachers favour various teaching methods. Consequently, e-learning involves more than simply reading online lessons.

Adaptive E-learning

E-learning is a large and complex field of research encompassing a *variety of learning and teaching paradigms*, such as constructivistic, serial, symmetric (Jain et al. 2002), cognitive, face-to-face, discovery, and managed learning (Lennon and Maurer 2003). In addition, various levels of pre-knowledge as well as progress and difficulties on lessons for individual learners have to be considered. As stated in (Jain et al. 2002), e-learning, even if standardised, tends to produce asymmetrical learning, as its tools reach out to a dispersed audience where individuals may arrive at different stages at different times, even if along a common learning trajectory. Furthermore, the personalisation of instructions and interactivity improves the knowledge acquisition process. For example, a learner in a classroom setting asks significantly less questions, whereas in an individual tutoring setting, a learner may ask or is required to answer a lot of questions in any learning session. Thus, the achievement of individually tutored learners' performance, as measured by test scores, may significantly exceed that of classroom colleagues; for details see (ADL 2001) and (Bloom 1984). These are some of the reasons for considering *personalisation* and *adaptivity* to be one of the key issues in modern e-learning environments.

Key Issues and Objectives

Following the observations and findings stated so far, it is worth mentioning that in order to offer the appropriate learning method and to compile the relevant learning assets and learning sequences for any individual learner, the gathering and analysis of *fine-grained user profiling information* is a serious technological challenge. Furthermore, just providing the technical solution of delivering learning content from static learning repositories will not meet all requirements for supplying teachers and learners with personalised and timely information. In particular, the *knowledge transfer process* defines the key issue within the context of technology-based instructional environments and it can be interpreted as a holistic phenomenon composed of two related streams: the *teaching process* (knowledge generation and delivery as well as assessment of knowledge acquisition) and the *learning process* (knowledge acquisition). Both of them have to be supported by a future-oriented approach.

Thus, the main objectives of an innovative solution for an e-learning system are:

1. personalised retrieval, management and presentation of relevant and timely information for learning activities,
2. support of various learning and teaching paradigms, and
3. improved knowledge of the users' behaviour in the field of human-computer interaction in general as well as related to the displayed learning contents in order to gain new insights and input for (1) and (2) as well.

Considering the above depicted aspects, we believe that a more extensive solution framework is needed, which allows the binding together of effective modern technologies and solution approaches in order to enhance the adaptation of knowledge provisioning and to increase the effectiveness of personalisation. This notion builds the basis of our solution approach, the AdeLE framework. Unlike common methodologies of tracking page views and mouse clicks, we advocate a combination of *fine-grained real time eye-tracking* and *content-tracking* operations for the user profiling as well as complementing the data stream by interactive system-user dialogs and online progress testing. Furthermore, in the field of information acquisition for the teaching and learning activities, we propose besides static learning assets also a highly dynamic, task-specific and personalised information retrieval component, which we call *dynamic background library*.

Going the right way?

To conclude this chapter, let us state that we are conscious and aware of the fact that personalisation and adaptation should not be considered as *universal goals or solutions for effective e-learning*. E-learning environments, adaptive systems and personalisation techniques have a lot of proven weaknesses and have been (often justly) criticised by experts of different fields.

Although we think that it is not necessary to repeat all drawbacks and problems of personalisation extensively in this paper, consider the following few examples of critical aspects regarding the application of personalised e-learning. From the knowledge delivery viewpoint, there are some cases where teachers want students to use exactly the same learning material in order to provide a common experience and thus, to foster community-based learning. From the viewpoint of knowledge acquisition and the support of different learning styles as well as considering some findings coming from other research fields, developers of adaptive systems should (a) exercise care in not allowing an *information overload* on screen in order to improve the effectiveness of working memory (for details about cognitive load theory see e.g. (Cooper 1998; Feinberg and Murphy 2000), (b) enable the *scrutability of the user profile* in order to give learners the overview and control of adaptational parameters, and (c) consider *privacy and security issues* e.g. due to the intrusive character of devices such as an eye-tracker system (see also Czarkowski and Kay 2003).

3. Related Research Fields

The purpose of this chapter is, on the one hand, to show that the ideas behind personalised e-learning are not as new as supposed. On the other hand, this fact underscores that the field is broad and has a high potential of interest and for research. Thus, in accordance to the basic issues behind the idea of the AdeLE solution framework, a selection of some interesting subjects related to the proposed system is discussed as follows.

Adaptive E-learning, Standardisation and Learning Repositories

The utilisation of adaptive multimedia systems as improved learning environments are well documented in research work (Brusilovsky 1998a; Brusilovsky 1998b; Hothi et al. 1998; Seeberg 2003), implementation concepts and systems can be found, for example in (Beaumont et al. 1995; Hockemeyer 1997; Boyle et al. 1998; ARIADNE 2003; García-Barrios 2001b). Tracking the behaviour of users and analysing their learning progress are not new research issues, but were demonstrated in classic systems already in the 1950's. Well known early systems are CLASS and PLATO (Crowell 1967; Modesitt 1974). In the present, novel user modelling techniques are important as they allow systems to personalise the human-system interaction processes (Conlan et al. 2002).

Well-defined learner model standards and specifications, like PAPI (Public and Private Information for Learner - IEEE), IMS LIP (IMS Learner Information Package) or GESTALT (Getting Educational Systems

Talking Across Leading-edge Technologies) already exist (PAPI 2000; IMS LIP 2001; Gestalt 1999). Furthermore, e-learning capabilities that enable interoperability, accessibility, structuring, packaging and reusability of Web-based learning content are also finding standardisation through advanced specification initiatives, such as SCORM (Sharable Content Object Reference Model). Also regarding courseware objects other well-known standards find broad application, as for example LOM (Learning Object Metadata) in order to support semantic enrichment, or IMS Simple Sequencing in order to define conditional interrelationships of different successive nodes along an adaptable learning path (LOM 2003; IMS 2003).

The examples shown in the previous paragraphs point out that adaptivity and personalisation constitute broad research fields with a relatively long history and a large number of significant results (see also Brusilovsky 1998b; Hothi et al. 1998; Beaumont et al. 1995). However, much work is still to be done towards existing or emerging issues and challenges, especially more generic solutions are needed.

Further, a lot of work is already done regarding the topic of learning repositories. In the field of static learning assets there exist various initiatives as listed in (NLII 2004), web information retrieval for assisting learning activities are discussed for example in (Liaw et al. 2003), and the novel idea of the dynamic background libraries is well documented in (Dietinger et al. 1999) and (Guetl 2002). Though, to our knowledge no integrative solution combining static and dynamic learning content in e-learning systems is available so far.

Eye-Tracking Research Field

The field of eye-tracking research is indeed an old but at present a very active discipline. Nowadays, eye- and gaze-tracking systems are found in several research fields, like scan-path testing on the WWW (Josephson et al. 2002), research in the area of aviation (Merchant 2001) or of driving environments (Hayhoe et al. 2002), computational studies about visual cognition (see Rao et al. 1997; Zhai 2003), design implications in web search tasks (Goldberg et al. 2002), human computer interaction (Ivory et al. 2001), and many others. Quite recently eye-tracking vendors began to implement real time eye-tracking analysis, but there is still a lack of integration in profiling systems and exploiting the data flow for personalised content compilation.

To sum it up, let us state that according to our extensive literature survey in the context of adaptive e-learning, (a) great research work has been done, and (b) several prototype solutions, tools and systems already exist. However, these are just isolated solutions, which cannot entirely satisfy the teachers' and learners' needs in order to improve a personalised semantic knowledge transfer. Thus, the *AdeLE framework*, which will be introduced in following sections, covers new ideas by means of providing a *modular and flexible architecture* for adaptive multimedia learning systems in order to enhance the *adaptive semantic knowledge transfer process* as well as by combining real time eye-tracking and content-tracking in order to enhance *fine-grained user profiling*.

4. Real-time Eye-tracking Information

One of the main aims within the scope of the AdeLE project is to observe users' learning activities in real-time by monitoring the major possible number of behavioural aspects and personal traits. Learner profile information of special interest for AdeLE are (a) *personal characteristics*, such as cognitive or learning styles, (b) *momentary states*, like tiredness or mental effort (see García-Barrios et al. 2004), as well as (c) *other indicators* during the learning process, such as objects and areas of focus, time spent on objects, frequency of visits, and sequences in which learning content is consumed (see Preis and Mueller 2003). The advantage of interpreting these data in real time lies in gaining prompt information about the user's state. By exploiting eye-tracking data combined with other user behavioural traits linked with the content provided, a *fine-grained learner profile* can be tracked by the system and applied e.g. for personalisation of learning content and navigation. Furthermore, based on this fine-grained learner information, the target of AdeLE is to gain an insight into the *learning strategies* that users apply when using an e-learning platform and to be able to detect patterns indicative of disorientation or other suboptimal learning strategies. At this point, it should be also mentioned that in order to interpret efficiently behavioural indicators, it is important to not rely exclusively on eye-tracking data, but to supplement it with information gained by direct and constant *user feedback*, i.e. learners must 'on screen' not only be informed of why/how adaptation happens but also get free control of the adaptation procedures.

Eye-Tracking Technology and E-learning

In terms of eye-tracking technology, eye movements, scanning patterns and pupil diameter are indicators of thought and mental processing involved during visual information extraction (Rayner 1998; Kahneman 1966). Thus, real-time information of the precise position of gaze and of pupil diameter can be used for supporting and guiding learners through their learning journey. Very roughly, eye movements can be divided into two components: *fixations*, i.e. periods of time with relatively stable eye movements where visual information is processed, and *saccades*, which are defined as rapid eye movements that bring a new part of the visual scene into focus. However, more important indicators can be gained by analysing both components together with other derived parameters. Finding out reliable parameters is one of the emerging aims of the AdeLE project. To emphasise the complex situation in this research field consider the following problems and prospects in context.

Gaze duration (i.e. time spent on an object) and fixations are not indicative of attention per se, because one can also pay attention to objects that do not lie in the centre of the focused region. Nevertheless, by considering other indicators, such as saccadic velocity, blink velocity and rate as well as eyelid's degree of openness, a better and more meaningful approximation can be gained. Saccadic velocity, for example, is said to decrease with increasing tiredness and to increase with increasing task difficulty (Fritz et al. 1992). Further, blink rate, decreasing blink velocity and decreasing degree of openness may be indicators for increasing tiredness (Galley 2001). Thus, if tiredness is identified, it should be possible through adaptive e-learning mechanisms to suggest optimised strategies such as the best time to take a break. At this point it is reasonable to also emphasise that the user should always retain the final say over whether to accept or reject the system's suggestions (we call that *controlled adaptation* or *non-intrusive adaptivity*).

AdeLE's Eye-Tracking System

At the present there basically exist two types of eye-tracking systems on the market: outside-in systems and inside-out systems. Outside-in systems are characterised by the fact that one or more cameras record the eye of the participant and trace the gaze in a scene through imaging algorithms. The cameras are positioned in front of the participant. One of the advantages of these systems is given by the fact that the camera can be integrated into the monitor, and therefore remains basically invisible (i.e. a relatively non-intrusive monitoring is possible). Inside-out systems are characterised by a special device that the participant has to wear on the head. The image of the eye is led into a mini-camera by using mirrors. This mini-camera records the eye and the actual line of vision is found out through imaging algorithms. More characteristics of both systems along with advantages and disadvantages related to the requirements of the AdeLE project are outlined in detail in (Pivec et. al 2004). For further detailed information about general eye-tracker characteristics refer to (Jacob 1995) and (Galley 2001).

For the purposes of the AdeLE project outside-in systems seem to be more suitable, hence they are less intrusive for the learner and support tracking of the user by regular e-learning lessons. Based on the project objectives and the requirements for the eye-tracking system, the AdeLE team decided to utilise *Tobii 1750*. Figure 1 on the next page shows the utilisation of the eye-tracker system within the AdeLE project, on the left side a user is being monitored on real-time by the eye-tracker during a learning session and on the right side the monitored results are examined. The Tobii 1750 is integrated into a 17" TFT monitor and can therefore be used for many forms of eye-tracking studies with stimuli like Web sites, slide shows, videos and text documents. Further, the Tobii 1750 does not show any problems with its functional re-acquisition from extreme head-motions. Another advantage is given by its high tracking quality, i.e. it can be used by young or old people, by persons with dark or bright eyes, by users with different ethnical-dependent anatomic eye types, by people with glasses or contact lenses as well as under varying environmental light conditions. More technical advantages of the system can be summarised as follows: a) high accuracy (0.5 degrees accuracy, bias error), b) compensation of unparalleled quality of head-motion and drift reduction, and c) binocular tracking with a frequency of 50 Hz. Further, the system provides a well-designed programming interface with which its automatic functionality can be configured, enabling no additional manual adjustments of parameters on the device. This interface is utilised to integrate the eye-tracking system into the AdeLE framework, as described in the next section.

Figure 1. Utilisation of the Tobii 1750 Eye-Tracking system.

5. Architectural Overview of AdeLE Framework

This section gives an overview over the functional and logical architecture of the AdeLE framework, as is illustrated in Figure 2 below. The main functional components are mainly divided into the following three logical parts: Core Module, User-centred Modules and Lecturer-centred Modules.

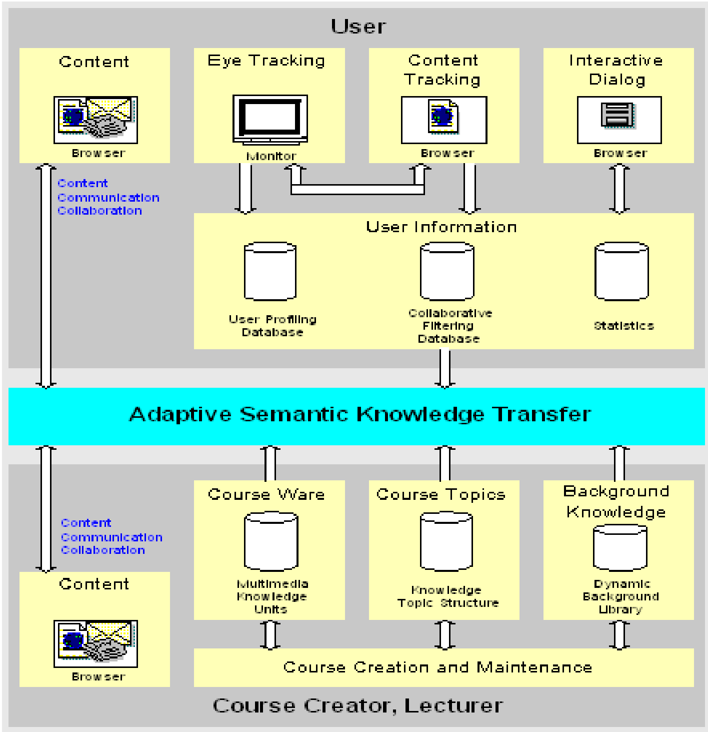

Figure 2. The architecture of the AdeLE framework.

Core Module

The *Adaptive Semantic Knowledge Transfer Module* (ASKTM) represents the core module of the framework. From a global point of view the ASKTM coordinates all the surrounding modules and sends and requests information to and from them. It compiles pieces of content and meta-information for delivery to the learners. Separate interfaces are provided for the other two groups of users: course creators (authors) and lecturers (teachers, trainers or tutors). For media and platform-independence, the information is provided in an XML schema and can be transformed into various formats. The process of content delivery is depicted in the upper left and lower left parts of Figure 2.

User-centred Modules

The upper right part of Figure 2 shows the user-centred modules for advanced user profiling. The core functionality for gaining enhanced and more precise user information is located in the combination of the *Eye Tracking Module* (ETM)and the *Content Tracking Module* (CTM). ETM in combination with CTM provides real-time fine-grained data regarding the user's reading and learning behaviour. The ETM also gives the system hints about concentration, excitement or tiredness of the learner, and consequently, inferring criteria to monitor efficacy aspects to the knowledge assimilation process.

The entire set of information of user interaction and behaviour is supplied to the *User Information Module* (UIM), which is in charge of managing the user modelling and profiling issues. In order to support user-controlled adaptation, the *Interactive Dialog Module* (IDM) allows learners to set and change user profile settings actively. Further, the system also can proactively force user interaction. For example, the latter module can be used to verify and if necessary adjust any automatically inferred user information. If tiredness is suspected, the IDM may also be used to suggest a short break or provide a relaxation exercise to the user. We have chosen the term 'user' at the upper-side of the framework, because lecturers may also interact with the system in order to achieve a direct tutoring intervention in the adaptation processes of the e-learning environment. The implementation of this feature is intended to allow overriding of automatically generated system decisions, e.g. to support hybrid learning techniques.

The UIM encompasses three user information databases of different granularity: the *User Profiling Database* (UPD), *Collaborative Filtering Database* (CFD) and *Statistics Database* (SD). The UPD holds fine-grained information about a wide range of user interactions (e.g. sequences of scanned and viewed pieces of information) and more abstracted values of user behaviour types (e.g. level of gained expertise in certain subtopics). Similar user profiles or user behaviour types are grouped and managed in the CFD (i.e. supporting stereotyped user-modelling). Through collaborative filtering, the system can proactively suggest particular pieces of information in proper media by exploiting the collective knowledge of user groups and their behaviour. Finally, the SD manages abstracted information in auser-independent level. Course creators and administrators may use valuable information (e.g. identified problematic areas of courseware sections) without violating the privacy of individual learners. The learning process will be improved, because the system will create or deliver adapted content by means of tracked statistical data (e.g. by delivering more images/tables for learners that have problems with large and complicated texts).

Lecturer-centred Modules

The lower-right section of Figure 2 shows the lecturer-centred modules of the AdeLE framework that are responsible for the course creation process. The *Course Creation and Maintenance Module* (CCMM) represents the core module for the entire course management and controls the *Courseware Module* (CM), the *Course Topics Module* (CTM) and the *Background Knowledge Module* (BKM). Course creators and lecturers can set up and maintain courses as well as request statistics about their courses. The CM manages pieces of information in different media types and an extensive set of metadata. This module (CM) can either store pieces of information locally or just manage metadata and include remotely located sources by caching them.

On the one hand, the CTM manages course content by just defining subsections using meta-descriptors, i.e. course creators only predefine subtopics and their relations at the time of course generation. During the learning process, users get dynamically proper and most recent pieces of information out fromthe pool of the CM. On the other hand, the CTM permits to manage a course topics structure and a thesaurus for providing automatically relations between subsections. The BKM dynamically provides additional information within the learning process and helps course creators to keep pace with most recent information.

Different Viewpoints on the AdeLE Framework

From the *point of view of learners*, the AdeLE framework provides an adaptive e-learning system with personalised views of the learning material, i.e. the content is adapted in accordance to pre-knowledge and learning progress, preferred media types, etc. Furthermore, real time eye-tracking can help to identify areas of understanding difficulty and enable the provision of selective additional information or explanation. A smart progress profiling keeps pace with learners' system interaction and may assist them at further learning sessions. In addition, learners can get a wide range of dynamic background information.

From the *point of view of lecturers*, the framework offers a wide range of helpful and smart features for courseware generation and maintenance. Assuming that courseware modules follow a separation of form and content, or at least follow a consistent style guide, it allows lecturers to create course ware by simply defining meta-descriptions of subtopics and their relations. Course authors can also create their own multimedia knowledge units applicable for course delivery and share them. In the processes of creating new knowledge units or updating information as well as defining background information for the learners, the dynamic background library assists the course creators and lecturers. The concept of dynamic background libraries is well documented in (Guetl 2002) and a prototype implementation has been developed by (García-Barrios 2001b). Statistical information (e.g. identified courseware pieces with understanding difficulties, subjects of most/weak interest) supports the maintenance of the courseware.

Based on the architectural overview of the AdeLE framework, a wide variety of applications scenarios are facilitated. However, in the first stage of the AdeLE project, research work is focused on the utilisation of real time eye-tracking and content tracking information. In order to get a view on the practical application of the AdeLE framework in this field of research, some application scenarios are shown in the following section.

6. Application Scenarios

By merging eye-tracking technology with proper content presentation the goal is to identify, evaluate and develop methods of adaptive instruction for personalised e-learning. Currently, the research efforts of the AdeLE team concentrate on three application areas, which are discussed in the following paragraphs.

Individual Learning Strategies

The first application scenario deals with the development of methods to extract individual learning strategies from the learner's gaze behaviour and adapt against the identified learning style. Comprehensive reviews of cognitive psychology research indicate that people exhibit significant individual differences in how they learn (Schmeck 1988; Glaser 1984; Robertson 1985; Honey 1986; Leutner 1998). A simple example being individuals who have a strong visual memory but weaker verbal processing will find text based material harder to process than individuals who have stronger verbal skills. In the traditional classroom environment a teacher has the chance to adapt or explain material to suit individuals' needs. In e-learning environments where a teacher is frequently not present, pedagogical material is nowadays more uniformly presented. In this environment information about the learner's gaze behaviour would be a great opportunity to optimise material to an individual's needs. For example, if somebody prefers text and ignores pictures the amount of pictures presented could be reduced, and vice versa.

Additional Context Specific Information

The second application scenario is defined by the use of the information gained from the specific content accessed by the user (specific words, paragraphs, areas of pictures, tables, and the like) in order to provide additional context specific information. For example, an animated picture could accompany textual information, whereas the integration of the picture proceeds in relation to the words or paragraphs accessed by the user (see Figure 3 below and Figure 4 on the next page).

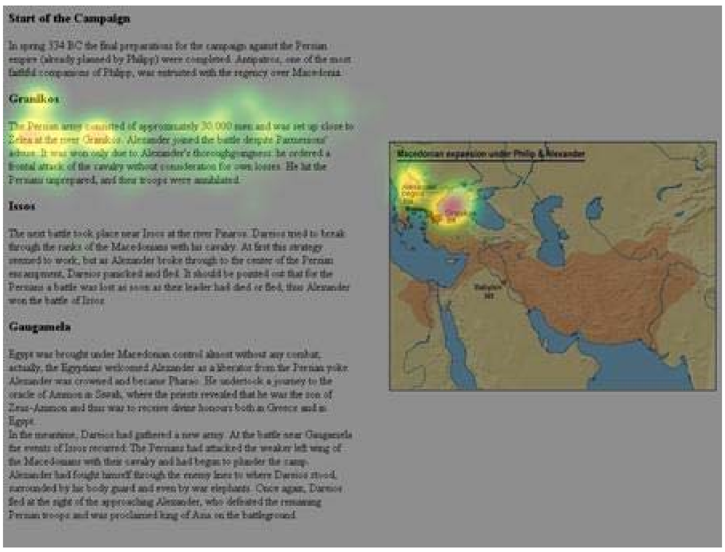

Figure 3. In an e-learning course concerned with Alexander the Great's Conquest of Persia, a map of Alexander's advance in the region is shown. The map content is updated in correspondence to the text paragraph currently read by the learner. In the example, the second paragraph ("Granikos") is being read and the map shows the journey of Alexander from Macedonia to Granikos (green, yellow and red areas indicate fixations and gaze duration).

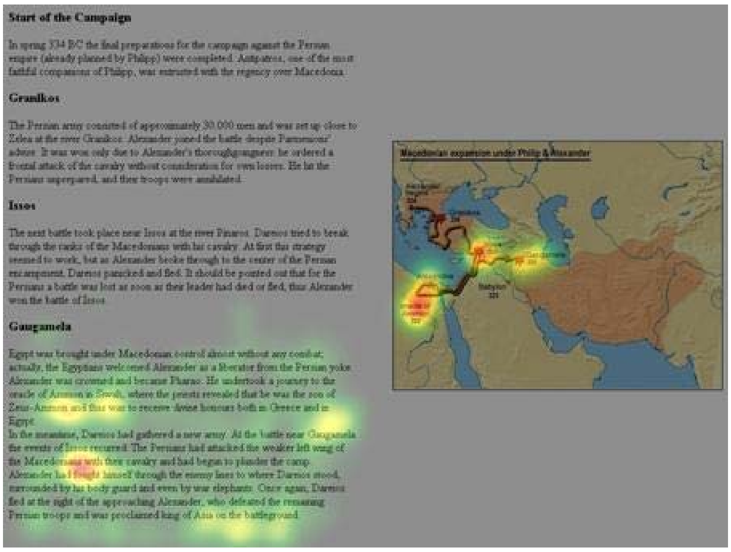

Figure 4. The reader has advanced to the fourth and fifth paragraph ("Gaugamela") and is automatically shown the corresponding map containing the passage from Issos to Gaugamela.

The AdeLE research team also aims at the possible application of the system in the field of high sensible knowledge transfer, such as training sessions in nuclear power plants, in the field of aviation techniques or in military, where it is essential that each section of a content unit has to be read by the learner. By means of the real-time user behaviour, unseen sections of content units provided to the learner are identified by the system and again will be supplied to the user at the following content units. Of course, this method can not reflect information about the knowledge acquisition and about pre-knowledge. However, information about content sections skipped by the learner are utilised to compile specific assessment tests to check the learner's knowledge about these particular concepts.

Appropriate Intervention Strategies

The third interesting application area of the AdeLE research work is based on developing and testing appropriate intervention strategies when the learner is found to be stuck. The e-learning environment might intervene when a learner is not focused on a relevant part of the computer screen, or is focused completely outside the task area for a certain period of time, or the eye gaze is sufficiently quick/jerky for a given period of time. Just to give one example, in case of knowledge acquisition problems for a particular content section more detailed content or background information can be provided to the learner.

Other Application Areas

Besides the above-depicted issues, innovative solutions as well as an improved and more profound understanding are expected in the following areas:

- Improved knowledge of the users' behaviour in the field of *human-computer interaction* in general as well as related to the displayed learning contents
- Improved and detailed course *progress tracking*
- Novel possibilities for identifying the most suitable *media and content presentation* within knowledge transfer environments
- Identification of *problematic areas* in the content flow and/or content structuring

7. Conclusions and Future Work

Evidently, the price of an advanced eye-tracking system plays a decisive role in the application possibilities of the AdeLE solution approach. Nevertheless, existing systems show that an eye-tracking device can be integrated into a standard monitor. Due to the continuing trend of rapid technical progress, it may be expected that in the next few years it would be possible to build a low-cost but high-quality eye-tracking system based on standard hardware components, which would be suitable for real-time analysis of eye-tracking information as described in this paper. Some results of the AdeLE project may contribute to find new ways of making advanced adaptive environments for teaching and learning feasible and affordable for institutions in a relative near future.

Potential target groups that could benefit from the presented ongoing research and proposed innovations based on eye-tracking supported real-time data capturing and adaptation-based systems are identified as follows:

- *Various end-users*
  Support of 100% knowledge acquisition in application fields such as aviation, traffic, different complex procedures, risk management, decision support, research on learning, and others.
- *E-learning platform and knowledge management platform developers*
  Inclusion of these innovative approaches and provision of better adaptive/adaptable platforms
- *Content publishers*
  Improvement of content structuring, development of user-centred contents and of contents supporting various learning stiles.
- *Eye-tracking system producers*
  Development of low cost eye-tracking systems, which are possible to apply in a standard computer working place.

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