AdeLE first prototype: experiences made

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Abstract: In this paper we describe first experiences with AdeLE prototype, a framework for adaptive e-learning utilising both eye tracking and content tracking technology. We outline features of the first prototype and their relevance for the user. We report more in detail about current research challenges where we observe users' learning behaviour in real time by monitoring characteristics such as objects and areas of focus, time spent on objects, frequency of visits, and sequences in which content is consumed. This research is focused on analysing eye-movement patters during learning and linking these patterns with cognitive processes. Possible areas of application are described, such as using the information about the position of the eye for providing additional context specific information to the learner. The framework ensures not only adaptivity to the users' preferences, knowledge level and the real-time tracking of their behaviour, but also the relevance, accuracy and reliability of the knowledge provided.

Keywords: real time eye tracking, adaptable e-learning, learning research, cognition
Categories: (H.4, J.4, K.3, I.5)

1 Introduction

Over the last 10 years the Internet has become an incredibly important media for learning. By now e-learning is not a foreign concept anymore; millions of pupils, students and employees make use of it. Sophisticated technologies and new didactic concepts have been developed with the aim to make learning more effective, less expensive and adaptable to the needs of the individual learner. One technology which has not been used in this context so far is eye-tracking. The study of eye movements pre-dates the widespread use of computers by almost 100 years [Javal 1878]. Eye movement research and eye tracking flourished in the 1970s, with great advances in both eye tracking technology and psychological theory to link eye tracking data to cognitive processes [Monty et al. 1976], [Senders et al. 1978]. Meanwhile eye-tracking is used to study behavioural, cognitive, neurobiological and clinical aspects of eye movements.

In our research we are concentrating on how information from eye-movements could be used to support the learning process. In most e-learning environments information is mainly provided by means of written text. Thus, reading this information is essential for learning. The characteristics of eye movements during reading have been studied in great depth [Rayner 1978] [Rayner 1998]. Eye movements vary as a function of word characteristics, legibility of the text, syntactic difficulty of the text, conceptual difficulty of the text, and whether it is being read silently or out loud [for review see Hyönä et al. 2003]. Furthermore, eye movements during reading can reveal significant differences between individuals. As a consequence, the study of eye movements during reading has considerable practical applications in education psychology [McKane et al 2001].

The presented research of AdeLE (Adaptive e-Learning with Eye tracking) project is focused on a new generation of adaptable knowledge transfer in e-learning environments [AdeLE]. This new and innovative approach strives to capture dynamically user behaviour based on a real-time eye-tracking system (see also [Pivec et. al 2004], [Garcia-Barrios et al. 2004]). We apply eye-tracking for more profound learning research and improvement of cognitive processes understanding to be able to support adaptive teaching and learning in a technology-based e-learning environment in the future.

2 Description of the AdeLE system

2.1 Real-time Eye-tracking (user tracking)

Defining reliable set of parameters is one of the emerging research issues in the AdeLE project. Eye movements, scanning patterns and pupil diameter are indicators of thought and mental processing involved during visual information extraction [Rayner 1998], [Kahneman et al. 1966]. Thus, real-time information of the precise position of gaze and of pupil diameter could 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. *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, which 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 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. 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 [Jakob 1995] and [Galley 2001].

For the purpose 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, we decided therefore to utilise "Tobii 1750", an outside-in eye tracker device integrated into a 17" TFT monitor. Thus, it can be used for all forms of eye-tracking studies with stimuli that can be presented on a monitor, such as websites, slide shows, videos and text documents. This system is easy to operate and all tracking processes run automatically. The calibration process is quick and has to be carried out only once for each individual. The device also 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 utilised 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. This system's programming interface is applied to integrate the eye-tracking system into the AdeLE framework, as described further in the paper.

2.2 AdeLE System Architecture

The aim of this subsection is to give an overview of the current system implementation. A detailed description of the server-side architecture is discussed in [Guetl et al. 2004].

To meet the requirements of a flexible system and to keep pace with the real-time processing of user behaviors, the AdeLE architecture consists of client-side and server-side system units, the implementation follows the service-based paradigm and is build on the OPENWINGS framework [OPENWINGS]. Figure 1 depicts the functional units and illustrates the information flow.

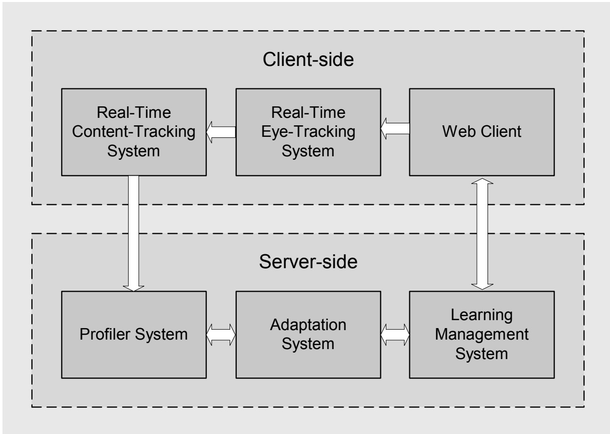

Fig.1: System Architecture of the AdeLE Implementation

On the client-side, the *Web Client* renders personalised content for the students and provides the user interface for students' interactions with the AdeLE system. As a further unit of the client-side, the *Real-Time Eye-Tracking System* reads the eye movements and concludes from different movement patterns user behavior sequences in real-time. Based on this information, the rendered content is processed by the *Real-Time Content-Tracking System* to get fine-grained information about the users.

On the server-side, the *Profiler System* manages the fine-grained user profiles based on form-filled attributes by the students, tracks the user behaviors by means of the fine-grained real-time information from the client-side, and adapts the user profiles. Based on these user profiles, the *Adaptation System* aggregates personalised learning content for each user, and the *Learning Management System* presents the proper learning assets and delivers the content to the client.

3 Description of the first prototype

Although the AdeLE architectural framework facilitates a wide variety of applications (see also [Pivec et al. 2004] and [García-Barrios et al. 2004]), this stage of the project's research work is focused on the utilisation of real time eye-tracking and content tracking information. In order to get an insight into the AdeLE prototype and a view on the practical application of the AdeLE framework within the field of research, the features supported in the first prototype are outlined. Some application scenarios are shown in the next subsection.

3.1 AdeLE prototype features

By merging eye-tracking technology with proper content presentation the goal of the research is to identify, evaluate and develop methods of adaptive instruction for personalised e-learning.

With real-time eye tracking user gaze data are gathered. Evaluation of users' eye gaze data gives us information about what the user is doing, e.g. learning or reading, looking at the pictures and illustrations or eventually struggling with systems' navigation. From *real-time eye tracking* data five different user behaviour parameters are reported to the AdeLE prototype: (i) learning, (ii) reading, (iii) searching in text, (iv) observing a picture or reading a text and (v) looking on the navigational elements. User parameters can be in range 0-1 expressing the probability of certain user behaviour. Reported user parameters trigger further various reactions of the system in terms of adaptation of the content and additional information offered to the user in next steps. Application of SCORM run time environment enables dynamic content sequencing, which calculates next steps and provides personalised content for the individual user. For instance, if some parts of the page were only scanned and the illustrations were not looked upon, the system will offer again these contents in appropriate context. By repeating and active scanning of contents the system will consult the user to determine the reason for such behaviour (e.g. user wants to get quick information about lecture content and structure, as opposed to scanning because the user already knows the details). The distinctive feature of AdeLE system is that next steps are not pre-defined in a fixed manner but depend on different user variables and highly correlate with user behaviour. Exchange of parameters is enabled by application programming interface that supports the communication of various systems within the AdeLE framework.

Further, the prototype can distinguish between (a) learning style of the user (e.g. visual, acoustic) and (b) cognitive style i.e. holist or analyst. Based on user questionnaires in the first place and enhanced by real time user observation, the AdeLE prototype can display adequately personalised course content. For example, to the holist the entire content is presented consequently in contrast to the presentation of the content to the analyst, where an overview of chapters and subchapters along with summaries is optionally offered. For users that have an acoustic learning style and according to cognitive theory that suggests breaking down content into segments that enable input through different channels, audio can be included as optional content presentation. Personalised content takes into consideration the user preferences as well as system observation.

Implemented course route tracking enables different statistical evaluation of the course route such as with which instructions and contents the user worked and duration, etc. These data can be applied for structure and flow improvement of the offered content.

The dynamic background library integrated in the AdeLE prototype makes it possible to provide additional information related to various concepts such as definitions, translations of various words, newest and more detailed concept explanation based on pre-defined queries, etc. Part of the additional information of the course content can be offered permanently and applied to bridge the gap between different knowledge states of the user. Part of the information can be offered "on demand" i.e. triggered automatically by mouse or by behaviour of the user. For example, using interaction with a mouse to move over a word and get explanation and / or translation. Based on users' gaze track it can be determined that certain word or sequence causes problems thus triggering the feature to display translation and additional explanation. According to user preferences additional explanation can be offered generally in different ways, e.g. within the chapter, at the end of the chapter or assembled at the end of the course [García-Barrios 2001].

Overall, the AdeLE framework aims at enabling innovative e-learning solutions as well as an improved and more profound understanding 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 content structuring

3.2 Application Scenarios

"In the 21st century, the education and skills of the workforce will be the dominant competitive weapon" said Lester Thurow.

A complex solution approach to manage the organisational knowledge merges courseware and simulations, as components of online training, with informational strategy i.e. informational databases and performance support tools. This makes e-learning a vital part of organisational knowledge management. Training and learning of employees is an activity that increases their competencies thus having positive influence on competitiveness of the organisation. AdeLE strives to provide individual technology enhanced support of learning. With appropriate learning support improvement of learning efficiency as well as better sustainability of the acquired knowledge can be achieved.

The AdeLE research team works on an application in the field of highly sensitive 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 and learned by the trainee. By means of the real-time tracking of user behaviour, unseen sections of content units provided to the learner are identified by the system and the system might intervene in an appropriate way. Of course, this method cannot reflect information about pre-knowledge. Based on the information about content sections skipped by the learner, adaptable and context specific assessment tests can be compiled to check the learner's knowledge about these particular concepts.

Currently, the research efforts of the AdeLE team concentrate on three issues, which are discussed in the following sections. The first issue is to develop methods to extract individual learning strategies from the learner's gaze behaviour and adapt to 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], [Honey 1986]. 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 individual needs. In e-learning environments where a teacher is frequently not present, pedagogical material is nowadays more uniformly presented. However, such environments have high capacity to provide adaptations in a variety of ways, as discussed in [Pivec et al. 2004]. In e-learning environment information about the learner's gaze behaviour would be a great opportunity to optimise material to individual needs. For example, if somebody prefers text and ignores pictures the amount of pictures presented could be reduced, and vice versa.

The second issue addresses the use of information about the specific content accessed by the user (specific words, paragraphs, areas of pictures, tables, and the like) to provide additional context specific information, thus supporting e-learning as well as knowledge management. 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. Further research questions related to this topic are "Does such an eye-triggered animation really help a student to learn?", "How should such an animation be integrated into the text to support cognitive processes?" or "How to support retention and comprehension?", among others.

The third research challenge is based on developing and testing appropriate intervention strategies when the learner is found to have problems. The e-learning environment might react in an appropriate way 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 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.

4 Conclusions and Future Work

By means of real-time eye tracking we strive to gain an insight into the strategies which users apply when learning by using an e-learning platform. Eye-movement patterns indicative of reading, learning or disorientation should be detectable with our system. The ultimate goal of our approach is to interpret various users' parameters in form of input data for an adaptable e-learning system that assists users to improve their learning behaviour, thus achieving better learning results in terms of decreasing time to acquire skills and competencies as well as improving sustainability of the knowledge.

In the context of user behaviour interpretation, it is very important not to rely exclusively on eye tracking data, but to supplement it also with constant user feedback. It is possible to suggest optimised strategies such as the best time to take a break, the best time for repeating specific learning content considering the forgetting curve [Davis et al. 2002] or suggesting better sequencing of the learning objects. However, the user will always retain the final decision on whether to accept or reject the system's suggestions.

Potential solutions that are based on findings 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:

- Support of learning processes in general and especially in application fields which need 100% knowledge acquisition such as aviation or traffic
- Development of human-centred learning solutions that include these innovative approaches and provide better adaptive/adaptable appliances
- Development of user-centred contents that support various learning styles

- Development of low cost attentive workplaces, where manifold bi-directional information flow between human and computer is supported

In general, some results of the AdeLE project may contribute insights and new ideas for the adaptive e-learning community. First promising experiences in applying the service-based paradigm for e-learning systems may inspire the community to build flexible and exchangeable components. Contemporary standards in the field of e-learning, such as SCORM, IMS LIP, PAPI and GESTALT, making great contributions to this field, but as yet do not fully meet the needs of adaptive e-learning and there is also a lack of mechanisms to describe the characteristics of real-time tracking systems. We hope that the AdeLE framework will assist in the enhancement of such standards.

Evidently, the price of an advanced eye-tracking system plays a decisive role in the application possibilities of the AdeLE solution approach. Nevertheless, the existing systems show that the eye-tracking device can be integrated into a standard monitor. Due to the continuing trend of rapid technical progress, we expect that in the next few years it will be possible to build a low-cost but high-quality eye-tracking system based on standard hardware components, which will be suitable for real-time analysis of eye-tracking information as described on this paper. This will enable to provide applications related to attentive workplaces for broad populations.

The AdeLE framework with the assets of extreme adaptation and personalisation to each individual user on various levels (e.g. macro level in terms of general adaptations of the course and micro level, where each page can be different, considering also the pace and momentary user performance) is the first step to innovation of human centered technology enhanced learning and knowledge management solutions.

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References

[AdeLE] AdeLE “Adaptive e-Learning with Eye Tracking” project page http://adele.fh-joanneum.at, accessed on 26.01.2005

[Davis et al. 2002] Davis, S. F. & Palladino, J. J., *Psychology* (3rd ed.), Prentice-Hall: Upper Saddle River, NJ, 2002.

[Fritz et al. 1992] Fritz, A., Galley, N., Groetzner, Ch., Zum Zusammenhang von Leistung, Aktivierung und Motivation bei Kindern mit unterschiedlichen Hirnfunktionsstörungen, *Zeitschrift für Neuropsychologie*, 1(1), pp. 79-92, 1992.

[Galley 2001] Galley, N.: “Physiologische Grundlagen, Meßmethoden und Indikatorfunktion der okulomotorischen Aktivität“; In Frank Rösler (ed.): Enzyklopädie der Psychologie, 4, Grundlagen und Methoden der Psychophysiologie, 2001, 237-315.

[García-Barrios 2001] García-Barrios, V. M.: "Dynamic Background Library: Learning on demand using Hyperwave eLearning Suite and xFIND"; Project at Institute for Information Systems and Computer Media (IICM), Graz University of Technology, Austria, 2001.

[García-Barrios et al. 2004] García-Barrios, V. M., Gütl, C., Preis, A., Andrews, K., Pivec, M., Mödritscher, F., Trummer, C., AdELE: A Framework for Adaptive E-Learning through Eye Tracking; in *Proceedings of I-KNOW '04*, Graz, Austria, 2004, pp. 609-616.

[Glaser 1984] Glaser, R., Education and Thinking: The Role of Knowledge, *American Psychologist*, 39, pp. 93-104, 1984.

[Guetl et al. 2004] Guetl, C.; García Barrios, V.; Moedritscher, V.: Adaptation in E-Learning Environments through the Service-Based Framework and its Application for AdeLE, in Proc. ELEARN 2004, Washington, USA, 2004

[Honey 1986] Honey, P., *The Manual of Learning Styles*, Peter Honey: Maidenhead, Berks, 1986.

[Hyönä 2003] Hyönä, J., Radach, R., Deubel, H., *The Mind's Eye: Cognitive and Applied Aspects of Eye Movement Research*, Amsterdam: Elsevier Science, 2003.

[Jacob 1995] Jacob, R. J. K.: "Eye tracking in advanced interface design"; In Advanced Interface Design and Virtual Environments, Oxford University Press, Oxford, 1995, 258-288.

[Javal 1878] Javal, E., Essai sur la physiologie de la lecture. *Annales d'Oculustique*, 79, pp. 97-117, 1878.

[Kahneman et al. 1966] Kahneman, D. & Beatty, J.: Pupil diameter and load on memory, *Science*, 154, pp. 1583-1585, 1966.

[McKane 2001] McKane, P.F., Maples, W.C., Sellars, P., McNeil, M., A comparison of auditory/language therapy with school visual support procedures in a public school setting, *Journal of Optometric Vision Development*, 32, pp. 83-92, 2001.

[Monty et al. 1976] Monty, R.A. & Senders, J.W., *Eye Movements and Psychological Processes*, Lawrence Erlbaum: Hillsdale NJ, 1976.

[OPENWINGS] OPENWINGS: Official Website; General Dynamics Decision Systems, last visit 2004-12-29, URL: http://www.openwings.org/

[Pivec et al. 2004] Pivec, M., Baumann, K., The Role of Adaptation and Personalisation in Classroom-Based Learning and in e-Learning. *Special Issue of J.UCS "Human Issues in Implementing eLearning Technology"* (http://www.jucs.org/jucs_10_1/), January, 2004.

[Rayner 1978] Rayner, K., Eye movements in reading and information processing, *Psychol Bull*, 85, pp. 618-60, 1978.

[Rayner 1998] Rayner, K., Eye movements in reading and information processing: 20 years of research, *Psychol Bull*, 124, pp. 372-422, 1998.

[Sanders et al. 1987] Senders, J.W., Fisher, D.F. & Monty, R.A. (eds), *Eye Movements and the Higher Psychological Functions*, Lawrence Erlbaum: Hillsdale NJ, 1978.

[Schmeck 1988] Schmeck, R.R., *Learning Strategies and Learning Styles*, New York, Plenum Press, 1988.