AdELE: A Framework for Adaptive E-Learning through Eye Tracking

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Abstract: In this paper we introduce AdELE, a framework for adaptive e-learning utilising both eye tracking and content tracking technology. The framework is based upon the combination of fine-grained real-time eye tracking with synchronous content tracking, a user profiler, an adaptive multimedia learning environment, and a dynamic background library. The framework ensures not only adaptivity to the users' preferences, knowledge level and the real-time tracking of their behaviour, but also ensures the relevance, accuracy and reliability of the knowledge provided.

Keywords: e-learning, learning on demand, adaptive hypermedia systems, attentive information system, dynamic background library, personalisation, user profiling, eye tracking.
Categories: H.3, H.4, H.5, J.4, K.3.2, I.2.6

1 Motivation

The knowledge transfer process within the context of technology-based teaching and learning environments can be interpreted as a holistic phenomenon composed of two related streams: the *teaching process* (concerning knowledge generation and delivery) and the *learning process* (concerning knowledge acquisition) [García-Barrios et al. 2002]. Furthermore, e-learning embraces more than simply reading online lessons. It is a large and complex field of research encompassing a variety of learning and teaching paradigms, for example: *constructivistic*, *serial*, *symmetric* [Jain et al. 2002], *cognitive*, *face-to-face* [Pivec 2000], *discovery*, *managed learning* [Lennon and Maurer 2003].

E-learning paradigms and implementations have brought many advantages to technology-based distance education. It is now possible to identify, analyse, track and monitor relevant aspects of instruction, such as different velocities, paths, or strategies of learning. Social aspects and problems, which are common in conventional face-to-face learning, such as censorship of information or racism, can be regulated or partially solved through mechanisms of e-learning.

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.

Our previous experience regarding the observation of user behaviour within the learning process has confirmed that learners tend to stick to distinct learning methods [Pivec 2000]. 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. These are two of the reasons for considering adaptivity to be one of the key issues in modern e-learning environments.

Many currently available solutions are not able to fulfil all the conditions needed to solve the main problems (and to achieve most of the aims) of semantic adaptivity and personalisation. Furthermore, they do not consider important pedagogical features in any depth. According to [ADL 2001], the value of personalised instruction is measurable by means of its effectiveness, e.g. a learner in a classroom setting asks on average 0.1 questions an hour, whereas in an individual tutoring setting, a learner may ask or is required to answer about 120 questions an hour. 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]).

In addition, we want to point out that - in some cases - holding an e-learning course as a completely virtual course might not reach the pedagogical advantages or objectives as also scheduling real-world lessons, i.e. the combination of e-learning with traditional face-to-face meetings allows a controlled regulation of symmetrical and asymmetrical learning. This technique is known as hybrid or blended learning, and comprises the balanced utilisation of synchron/asynchron, online/offline as well as virtual/non-virtual knowledge transfer phases.

Taking into account the above depicted aspects, we are of the opinion that a more extensive solution framework is needed, which allows the binding of effective modern technologies and solution approaches in order to enhance the adaptation of knowledge provisioning and to increase the effectiveness of personalisation. Within the bounds of AdELE we use an eye tracking system in order to deliver interfaces adapted to users' needs and to improve content adaptation according to the gained behavioural information of the user. Thus, the need emerges to search for and define new useful parameters, which enable a deeper insight into learners' behaviour during the learning process.

2 Adaptivity and Personalisation in E-Learning Environments

Tracking the behaviour of users and analysing their learning progress are not new research issues, but were demonstrated in classic systems such as CLASS and PLATO (see [Crowell 1967] and [Modesitt 1974]). Modern user modeling techniques are important, as they allow systems to personalise the human-system interaction [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. Furthermore, e-learning capabilities that enable interoperability, accessibility and reusability of Web-based learning content are also finding standardisation through advanced specification initiatives like SCORM (Sharable Content Object Reference Model). This brief introduction of some aspects in context exemplifies - and may also clarify - that adaptivity and personalisation constitute broad research fields with a relatively long history and a large number of significant results (see also [Brusilovsky 1998], [Hothi et al. 1998] and [Beaumont et al. 1995]). However, much work is still to be done toward existent or emerging issues and challenges.

In this paper we want to strongly emphasise the need for profiling more finely-grained user information and - in agreement with [Conlan et al. 2002] - of structuring fine-grained, standardised, and adaptable learning objects. Current techniques are not able to derive fine-grained information about users' behaviour. Rather, they typically provide larger-grained information such as the monitoring of mouse clicks and mouse movements, and determining how long a user stays on a single page.

3 Adaptivity through Eye Tracking

AdELE defines an innovative framework for enhancing adaptive and personalised knowledge transfer processes. This is done by exploiting the advantages of merging real-time content tracking and real-time eye tracking technologies at the user's side of the system, and encompassing the functionality of a dynamic background library at the content delivery side. Let us describe which characteristics of eye tracking systems are relevant and useful to support the real-time user profiling mechanisms with the purpose of enhancing personalisation and adaptivity.

Very roughly, eye movements can be divided into two components: *fixations* and *saccades*. Fixations are periods of relative stability during which part of the visual scene is focused upon in the centre of the fovea [Jacob 1995]. During fixations, visual information is processed. Saccades are very rapid eye movements, which bring a new part of the visual scene into focus. During saccades, little or no visual processing can be achieved. Fixations last about 100 to 400 ms and their velocities usually go up to about 100°/s. Saccades last about 25 to 100 ms and exhibit velocities in a range between 200°/s and 700°/s [Salvucci and Goldberg 2000]. The smaller eye movements and tremors, which occur during fixations, often have little meaning in higher-level analysis.

The *fixation duration* is the interval between the end of one saccade and the start of the next saccade. The *gaze duration* is the time spent on an object. Fixation and gaze duration are not indicative of attention per se, because one can also pay attention to objects, which do not lie in the foveal region. One must differentiate between the users' objective behaviour (eye movements), their latent cognitive operations, and their subjective impression [Galley 2001]. *Saccadic velocity*, which is closely related to saccadic amplitude and only assessable to eye tracking systems with high temporal resolution, can serve as an indicator for activation in the sense of tiredness or mental effort. Saccadic velocity is said to decrease with increasing tiredness and to increase with increasing task difficulty [Fritz et al. 1992]. Furthermore, *blinks* are interesting for our purpose. To blink means to close the eyes for a very short period to cover them with a thin film of tears [Galley 2001]. *Blink velocity* and *frequency* together with the *eyelids' degree of openness* can provide information on the user's tiredness level. Increasing tiredness is said to be indicated by increasing blink rate, decreasing blink velocity and decreasing degree of openness [Galley 2001].

In the AdELE framework, the intention is to 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 (see also [Preis and Mueller 2003]). It is hoped thus to gain an insight into the strategies which users apply when using an e-learning platform and to be able to detect patterns indicative of disorientation or other suboptimal learning strategies. In the context of user behaviour interpretation, it is very important to not rely exclusively on eye tracking data, but to supplement it with constant user feedback. It should be possible to suggest optimised strategies such as the best time to take a break. The ultimate goal of our approach is to assist users to improve their learning behaviour. The user will always retain the final say over whether to accept or reject the system's suggestions.

4 The AdELE Framework

The architecture of the AdELE framework is shown in Figure 1 (see next page). The core module is the *Adaptive Semantic Knowledge Transfer Module* (ASKTM). Taking a global view, the ASKTM coordinates all the surrounding modules and sends and requests information to and from them. The ASKTM 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. Content delivery is shown in the upper left and lower left parts of Figure 1; XML-based interfaces for module intercommunication are also important for interoperability.

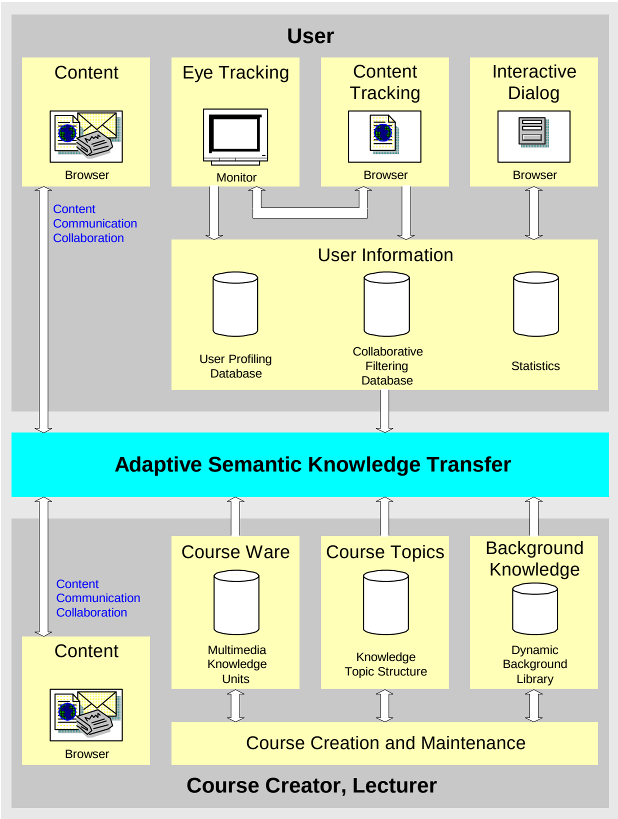

Figure 1: The architecture of the AdELE framework.

User-centred modules for advanced user profiling are shown in the upper right part of Figure 1. 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, infering 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). The *Interactive Dialog Module* (IDM) allows users 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, IDM also may 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. 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 a user-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 for the course creation process are shown in the lower-right section of Figure 1. 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 *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. 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. At the time of learning users get dynamically proper and most recent pieces of information out from the 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.

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 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 courseware 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 2001]. Statistical information (e.g. identified courseware pieces with understanding difficulties, subjects of most/weak interest) supports the maintenance of the courseware.

5 Concluding Remarks

The AdELE framework utilises the possibilities of evaluation and analysis of real-time eye tracking and content tracking to support adaptive teaching and learning in a technology-based e-learning environment.

Some of the expected benefits include [Pivec 2003]: improved knowledge of users' behaviour, fine-grained recording of consumed content and cognitive processes, identification of possible perception problems, development of correction and adaptation mechanisms in case of problems, identification of problematic areas in content flow or structuring. These results may find application in some of the following potential target groups: eye tracking system producers, hardware producers and content publishers. Thus, 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. Standardisation work regarding adaptivity and personalisation in e-learning is underway in well-known institutions such as ADL and IEEE. Standards as SCORM, IMS LIP, PAPI and GESTALT are making great contributions to this field, but as yet do not include mechanisms to describe the characteristics of real-time tracking systems. We hope that the AdELE framework will assist in the enhancement of such standards.

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