State of the Art: Adaptive Hypermedia

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1. Introduction

Adaptive Hypermedia (AH) is one of the most promising application areas for user modelling and user-adapted interaction techniques [Brusilovsky, 94]. AH systems can be useful in any situation were the system may be used by people with different goals and knowledge and where the hyperspace is reasonably large. Users with different goals and knowledge may be interested in different pieces of information presented on a Hypermedia page and/or may use different links to navigate to those pages. AH tries to overcome this problem by using knowledge about a particular user, represented in the user model, to adapt the information and links being presented to the given user.

From the perspective of M-Zones, Adaptive Hypermedia and the techniques researched in the broader adaptive eLearning domain have implications for personalisation in many facets of Smart Space design. These facets include –

- Content delivery (personalisation of content to users requirements, adapting to the users device and surroundings)
- Personalised views of a Smart Space (analogous to views in Databases; Smart Space visualisation – spatial or service based – may be adapted to the users preferences)
- Personalised/Adaptive service composition (adaptive navigation and presentation techniques utilised in AH may influence to customised combination of services to fulfil the users requirements)
- Adaptive management of services (as services are delivered across diverse smart spaces they may require resource management based on the unique characteristics of the Smart Space).

2. Overview

The underlying principles of software and information adaptivity may be divided into three discrete layers – the objectives of adaptivity, the techniques used on those objects and the axes across which those techniques or methods are employed. The primary field in which these objectives, axes and methods have been examined is in the eLearning domain, principally in the research area of adaptive hypermedia

Adaptive Hypermedia

Adaptive Hypermedia (AH) attempts to alleviate some of the difficulties encountered in Hypermedia systems by adapting the system individually for each user. The system collates information about each user into a user profile and this model is used to make assumptions about how best to change the system to benefit an individual user. The system may infer user objectives and help the user to discover the scope of information available or delineate a relevant path to get to the information required [De La Passardiere, Dufresne 92].

Adaptive systems infer the requirements of a user and modify the system accordingly. This introduces the problem of balancing control between the user and the system and the issue of the extent to which a user should be made aware of system made changes i.e. the transparency of the adaptivity. The correctness of assumptions made by the system cannot be guaranteed. This argument implies that users should be able to control the system adaptivity. Adaptable changes are those which originate from and are controlled by the user. Adaptive changes originate from and are controlled by the system [Fink et al 96].

The system adaptivity may be hidden entirely from the user so that the user is unaware of changes made by the system on her behalf. Alternatively the adaptivity may be negotiated with the user, allowing the user to accept or reject modifications suggested by the system. The modifications may be visible to the user but the user may not be able to change them. For example a link which is visible as a link, but dimmed and inaccessible to the user.

Users should have some control over the adaptivity but should not have to control it continuously [Espinoza, Hook 95]. System designers must attempt to strike a balance between the control allowed to the user and the ease of use of the system. It is imperative that users should not be surprised, disoriented or displeased by the changes made by the system [De La Passardiere, Dufresne 92]. When the usability of the interface is in opposition to the potential effectiveness of the system, the designer must attempt to provide adequate balance.

So what features of the system are modifiable? The system may customise the link structure or format which is offered - this is known as adaptive navigation. Similarly the system may vary the content displayed - this is known as adaptive presentation. The system may adapt the modality of the content or the prominence of links or content. Orientation aids and search facilities may be included, omitted or highlighted depending on the information contained in the user model and the rules used to apply the changes [Kay, Kummerfeld 95][Fink et al 96].

Adaptive Hypermedia in Educational Systems

Much of the focus in adaptive hypermedia for educational courseware has attempted to alleviate the difficulties of content comprehension (cognitive overload) and orientation (so-called *'lost in hyperspace'* [Laurillard, 93]). Adaptive presentation techniques which effect changes to both the selection of different media depending on a users preferences and adaptation of the content based on an individual's user model are beginning to show success. Also the use of adaptive navigation which effect changes to the link structure between elements of the hypermedia courseware based on an individual user's (mental) model, has proven effective since learners using such systems have demonstrated faster learning, more goal-oriented attitude and take fewer steps to complete a course.

To achieve the maximum effectiveness from the use of non-adaptive Hypermedia in an educational context there are some features of learners that are particularly significant. These include preknowledge, cognitive style, maturity, general ability, confidence and motivation. These features influence the ability of students to accept effectively the additional mental load caused by the need to monitor and self-evaluate as well as learn [Specht, 98].

Although increasing learner control is thought to increase the learner's motivation and engagement, results in performance using adaptively controlled environments have been superior to systems within which the user is left to their own devices [Specht, 98]. Studies have shown that users of educational

Adaptive Hypermedia systems are faster, more goal-orientated and take fewer steps to complete the course. It is claimed that Adaptive Hypermedia learners are less likely to repeat the study of content they have already covered [Eklund, Brusilovsky, 98].

Adaptive Axes

There are several adaptive axes that may be usefully employed in software and information adaptivity. These axes include adaptive navigation, structural and historical adaptation and adaptive presentation.

Adaptive Navigation

Adaptive Navigation attempts to guide the student through the system by customising the link structure or format according to a user model. The form of adaptive navigation will determine the level of guidance and freedom granted to the student within the system. Hypermedia experienced learners are known to be more likely to navigate in a non-linear way. Similarly learners who are familiar with the subject matter are more likely to navigate non-linearly and therefore reap the benefits of Hypermedia learning [Eklund, 95].

Structural Adaptation

Structural Adaptation attempts to give the student a spatial representation of the Hyperspace environment. This representation is based on the user model and is hoped to provide the student with a sense of position within the environment and a sense of the size of the environment itself. Overview maps, local maps, fisheyes, filters and indexes are all structural aids which the system may adapt for the student.

Historical Adaptation

Historical Adaptation attempts to give a time context to the student by adapting representations of the student's path through the system. History trails, footprints which are made by the system, landmarks which are made by the student and progression cues may be customised by the system for the student.

Adaptive Presentation

Adaptive Presentation is the customisation of course content to match learning characteristics specified by the user model. The granularity may vary from word replacement to the substituting of pages or the application of different media. Content may be customised to contain additional information, pre-requisite information or comparative explanations.

This form of adaptivity may be implemented by fragmenting the constituent content components into discrete words, phrases or paragraphs. These components of pagelets constitute a discrete unit of information about a concept. The pagelet is displayed if the user model conforms to required conditions for the display of that pagelet. For example, if a student has not covered a pre-requisite concept for a given page the relevant pagelet may be included.

With this approach different pagelets may be displayed for different students. An example would be a technical term or acronym with which the student is unfamiliar. The system may substitute the unfamiliar content until the student can be introduced to the technical term or acronym.

If the courseware is constructed dynamically each student may potentially see an individually tailored course that is different to the course displayed for all other users.

3. Analysis

The techniques utilised in adaptive software and the methods used to realise these techniques in different systems (described above) have implications for how adaptive information services may be implemented within an M-Zone. Core to many of the adaptive information services (Interbook, PLS, AHA) is some form of concept model. Each of these systems takes a bespoke approach to developing the concept models and the vocabularies used to describe those models. In an smart space environment, where automatic sourcing of content, service combination and common user models are envisaged, it is desirable that the vocabulary, and by implication the ontology structuring that vocabulary, should be common between, or at least discoverable by, the different services. Another alternative to this approach is that the services may attempt to approximate mappings between subsets of the vocabularies.

3.1 Service versus Stand-Alone System

The majority of Adaptive Hypermedia Systems are designed to exist as stand alone systems (Interbook, AHA). KnowledgeTree [Brusilovsky, 02] and PLS [Conlan et al, 02] however are two AHSs that take different approaches to exposing their adaptive content as services. Indeed neither KnowledgeTree or PLS should be viewed as traditional AHSs as they are designed to source content and functionality (such as Learner Management, Collaborative Tools, Testing Services) externally, not encapsulating all functionality into a monolithic core. However, they take quite different approaches to this sourcing.

PLS utilises a standards-based API (based on ADL SCORM 1.1) to interface with other compliant systems. In this way it can integrate with a Learner Management System (LMS) and pass user and assessment information back and forth between the systems. The PLS service is based on the notion that an adaptive content provider should be a service provider rather than a repository for extraction of content. Communication between PLS and a learning portal (or LMS) is achieved by enhancing the SCORM Runtime Communication API as used in SCORM v1.1.

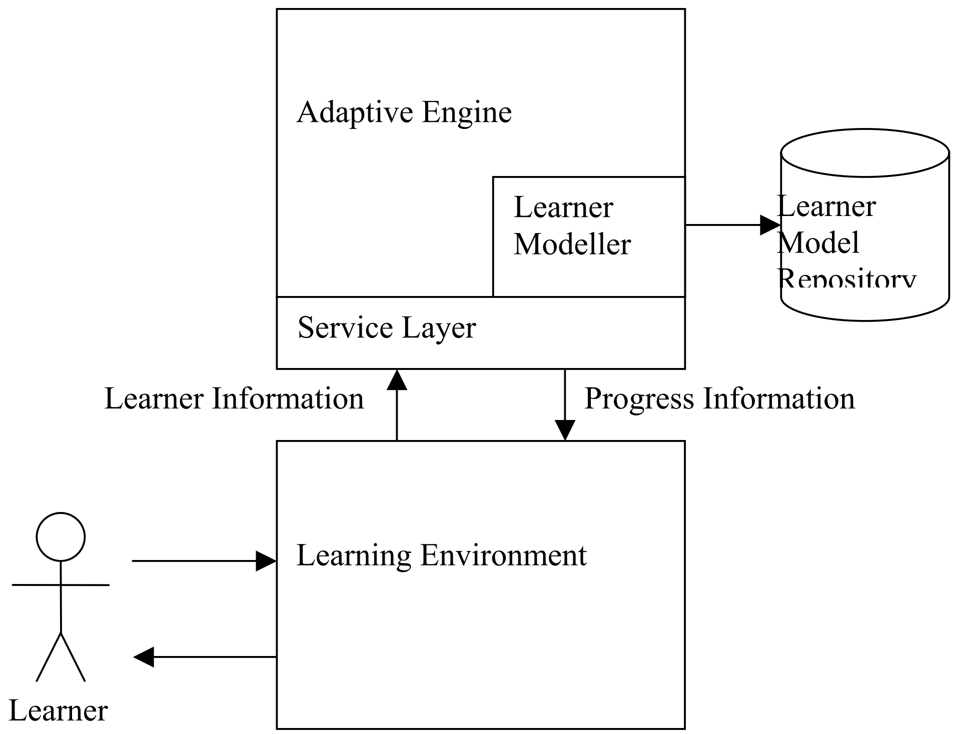

Figure 1. Learning Portal and Adaptive Service Interface

This requires a modification to the HTML frame layout for the PLS to enable calls to API functions residing on the LMS from PLS content. The actual API calls used are the same as those used in SCORM v1.1 as the API is designed to get and set values that are separately defined by an external data model. The remote PLS calls the Content Interworking API to access the data model on the Learning Portal (or LMS).
The learning content (visible on the learners screen) and JavaScript API (via a hidden browser frame) are delivered to the learner's browser. An API function, (which is in the hidden frame) is called from the content frame e.g. LMSGetValue("cmi.core.leason_status")). The hidden API frame then communicates the request to the Learning Portal (or LMS). The Learning Portal returns the value (in this case of cmi.core.leason_status) to the API Frame. The API function returns the value to content frame from which it may be passed back to the Adaptive Hypermedia Service (Figure 1).

Using these services, the deep complexity of the various meta data models (content, narrative, user) are simplified. The exported information model of the learner (and her performance) is made available via the API. The modified SCORM v1.1 interface facilitates integration with IMS and SCORM Compliant LMSs with only very minor adjustment of the information model passed between the Learning Portal (LMS) and the Adaptive Content Service. There is no change to the actual API function signatures [Conlan et al, 01].

Both PLS and the LMS maintain their own user information repositories, however. This approach was adopted in PLS as much of the user information and the way it is characterised is specific to the forms of adaptivity it is applying. In many regards the user modelling is one of the main distinguishing features of PLS. Some aspects of PLSs user model may be shared given a common vocabulary and framework, however others may still remain proprietary.

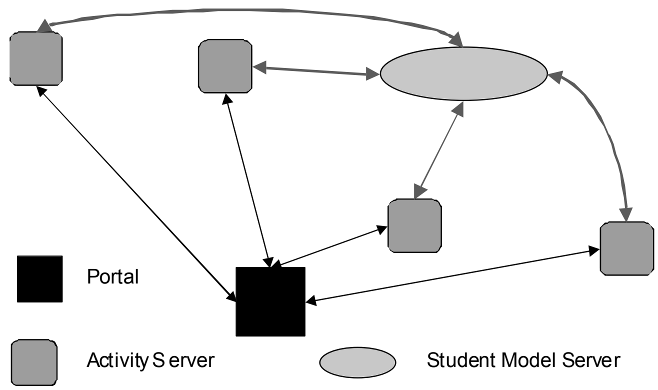

Figure 2: Main components of the KnowledgeTree distributed architecture.

The goal of KnowledgeTree [Brusilovsky, 02] is to replace the current monolithic course management systems (CMS) such as Blackboard or WebCT with a community of communicating servers. The architecture anticipates the presence of at least three kinds of servers: activity servers, learning portals, and student model servers (Figure 2). A *learning portal* plays a role similar to modern CMS. It allows a teacher to design a course and manages the student interaction with the course. The difference with CMS is that the learning content (activities) resides not in the portal, but in multiple distributed *activity servers*. An activity server plays a role similar to an educational repository in the sense that it hosts some (usually specialized) learning content. Unlike repositories that are essentially pools for storing learning materials that can be copied and inserted into courses, an activity server is responsible for both storing, and delivering *learning activities*. A portal has an ability to query activity servers for relevant activities and launch remote activities selected by students. An activity server is able to inform portals about available activities and provide a complete support for a student working with one of its activities. *Student model server* collects data about student performance from each portal and each activity server that work with a student. In exchange, it provides information about the student that can be used by adaptive activity servers to personalize their communication with the student. The presence of multiple adaptive activities requires a centralized user modelling architecture.

KnowledgeTree considers the standards-based model as not appropriate for adaptive distributed content and argues for a 3-component model (portal – content – student model server). PLS is structured to work within existing courseware management systems (CMS) that are completely static and thus consider adaptive services to be the main providers of adaptivity. It is assumed that that adaptive selection and structuring of content can only be done by a service. In contrast, KnowledgeTree allows for different kinds of portals – some can be as static as existing CMS, but some can be adaptive. In this vision, an adaptive portal can provide different adaptive support such as, for example, as adaptively selecting the best of existing static or adaptive content and adaptively arranging it for the student.

3.2 Adaptive Navigation Techniques

From a HCI perspective both AHA and Interbook use visual aids to indicate that different material is available to the user. In AHA [De Bra, Calvi, 98] [De Bra, Calvi, 97], the user model is constructed of user preferences indicated by the user directly, user knowledge initialised by stereotype and an overlay model which consists of boolean variables - true if a concept is known and false if the concept is not known. Adaptive navigation is implemented by links with three possible states - desired, undesired and uninteresting. The standards colours of WWW browsers are used - blue links are desired, purple links are uninteresting which implies the information has been visited and does not represent new information to be learned and dark grey links indicate undesired information for which prerequisites have not been covered.

Adaptive navigation in Interbook is implemented by link annotation using checkmarks and coloured balls. Annotation refers to adding information to a link so that the user has more of an idea of where the link will lead and whether it complies with the current objective of the user. Link annotation allows the user to be advised as to the degree of relevance the system applies to a link on the basis of the user model, and the user may then choose their own path. A link can have a number of different states the values of which may be displayed to the user by colour, icons, or font formats.

World Wide Web browsers currently use link states with two values - visited links (the default for which is purple) and unvisited links (the default for which is blue). Adaptive Hypermedia Systems can extend this idea to show links with three states to signify concepts that are learned, well-learned or unknown. Links with up to six states have been implemented in Adaptive Hypermedia systems: visited, unvisited, current, suggested [Eklund, Sawers 98]. The link may be changed to a light colour to suggest that the link is dimmed - this gives the effect of hiding without restricting the user. Annotation gives the user a degree of freedom and supports stable ordering and the formation of correct mental maps [Eklund et al 97].

In Interbook green ball and bold text designates the state of the link as ready and recommended which implies that all prerequisites are well-learned or at least learned. A red ball and italic text designates a link that connects to content that is not ready to be learned which suggests that some prerequisites are not yet learned. A white ball is used when the link connects to information that is not new implying that all outcome concepts are learned or well-learned. Checkmarks by a link show that a link has already been visited. If the link is small then the content behind the link is known implying that learning has started. A medium checkmark designates content that is learned, while a large checkmark indicates content that is well-learned.

The mechanisms used in AHA and Interbook for implementing adaptive navigation do not restrict the learners ability to follow a link, they indicate the suitability of the information for the learner. This principal may be employed in other facets of Smart Spaces, helping to guide the user without limiting their options. Other navigation support techniques include –

Relevance - Link adaptivity may require the system to decide on the relevance of certain sections of the course content to a particular user at a particular time. This decision is reached based on the information in the user model. As an example the decision may be based on the current objective or goal the system has inferred for the user. If a link connects to information which is not required to meet the current goal, the link may be marked as irrelevant. Similarly, the concept to which a link is connected may require knowledge of concepts that the user has not yet covered. These links may be marked as irrelevant at this time.

Direct Guidance is provided by the system deciding where the user should link to next and presenting the user with this option. This is also called curriculum sequencing as the system enforces a path through the course. This path is customised for that particular user but the advantages of Hypermedia are lost when the user cannot organise their own learning through the Hyperspace. When link annotation and direct guidance are offered together, users who are not confident of their ability to work through the course independently are more likely to click on the next button and accept direct guidance [Eklund, Brusilovsky 98].

Link Ordering is when the system sorts a list of links according to their relevance to the user. The system filters the links on the basis of the user model and presents the list with the most relevant links displayed at the top. This type of link adaptivity is often used for indexes or table of contents. A user who is inexperienced with the content of the course or with Hyperspace generally can be disoriented by a link order which is unstable.

Link Hiding restricts the navigational choice offered to a user. The system decides what links are not relevant to the user and changes the format to that of regular text so that the link is not displayed as a link. The link may be removed completely so that the user cannot access it even accidentally [De Bra, Calvi 98]. Link hiding can reduce the cognitive load on the user and conceal the complexity of a course while supporting the stable ordering of links. However, the usability of link hiding is questionable for a number of reasons. Users do not like to be restricted. There is a danger that the user will form an incorrect mental map of the Hyperspace. A sense of completion of the course will be difficult to attain when the user cannot be confident that all the links have been displayed.

3.3 Adaptive Presentation Techniques

When considering the presentation of information to the user both AHA and PLS utilise fine-grained pieces of content. In AHA adaptive presentation is implemented through conditional inclusion of fragments depending on the user model. Alternative presentation and hiding of text is also used depending on the inferred knowledge of the user. The system will switch to verbose mode for a novice user who has just started to use the system. A concept explanation is included in the current page if it is a prerequisite concept for that page which has not been covered. Similarly if a technical term has not been covered a substitute will be used. For example the word page is used instead of the term node until the description of a node is encountered by the user and marked as encountered in the user model.

PLS also uses page fragments, called pagelets. The metadata driven multi-model approach, upon which PLS is based, has a minimum of three models – Content, Narrative and Learner. The Content Model contains metadata descriptions of the actual small size learning objects (pagelets). The Narrative Model only refers to concepts which may be selected as part of a course. There is no direct reference between the narrative model and actual content. This is the primary point in which PLS and AHA differ. In AHA the logic governing the adaptivity is coupled with the content. Indeed, as the logic is primarily implemented in JavaScript the content and logic are an integral unit. With PLS, however, the mapping between narrative and content is performed at run-time by the service engine, which reconciles the metadata imperatives of the narrative model with the metadata of the content model maintaining a separation of logic and content. The narrative and content models are linked via a shared (or mapped) metadata vocabulary. This vocabulary used in PLS is an extension of the IEEE LOM and ADL SCORM. From a Smart Space perspective it is attractive to retain this separation as the service that delivers the expertise (or narrative in PLS terminology) may not be the same service from which the content is sourced. With the separation of the AHS into three discrete models – Learner, Content and

Narrative – PLS facilitates the maximum reuse of expertise (narrative model) and learning material (content model). Multiple candidates may be present in the system to instantiate the models. For example, there may be several narratives used to teach a single course. An appropriate narrative is selected based on the learner's preferred learning style. Similarly, appropriate content may be selected based on their preferred visual style.

3.4 Representing Expert Knowledge and Experience

The problems faced by the application of ITSs in the real world is one of the main driving forces behind the development of authoring environments for construction of ITS. Again the reuse of learning objects across multiple ITS systems is limited if not at times impossible. Likewise the instructional strategies developed by the domain expert were even less reusable. For successful development the system has to have some mapping between the high level pedagogy described by the author and the low level intelligence to be interpreted by the ITS during delivery. REDEEM (Reusable Educational Design Environment and Engineering Methodology) focuses on authoring pedagogy rather that on helping instructors create domain material. It offers a compromise between the static but simple CBT and the dynamic, albeit complex, ITS. REDEEM and PLS are some of the new generation ITSs and authoring tools aimed at creating ITSs in ways that require less effort, require less training and knowledge, provide help for authors to articulate their knowledge, support good practice or enable rapid prototyping [Murray, 99]. REDEEM's main goals are to: a) allow classroom teachers and trainers to construct ITSs in a reasonable timeframe; b) support reuse of existing material; c) focus on the authoring of pedagogy; and d) exploit the symbiotic relationship between psychology and reusable ITSs – using research to inform the design of ITSs, which can then be used to test the theories embedded within it, which in turn can inform developing theories of instruction and learning [Major et al, 97].

While not strictly an AHS REDEEM provides a means to creating ITSs that embody the teacher's experience and expertise, in a similar way to PLS.

4. Research Directions

Some research directions that have been identified with relation to software adaptivity are:
One of the key areas of interest both in the Smart Spaces and with respect to eLearning specifically is the research are of service integration. Traditional LMSs are monolithic systems that attempt to provide all functionality at the core. The disadvantage of this approach is that often users (in this case learners) do not always want/need all of the functionality or the functionality provided does not fit their requirements. In this case allowing the user/learner to construct their own learning environment from a selection of services may be desirable.
Related to the issue of service integration is the research area of terminal adaptivity, i.e. adapting the content delivered to the platform it is being delivered on. The separation of content and rendering is part of the solution to this issue. Appropriate models of the target platforms, however, do not exist and will be a necessary component in the adaptation process.
On going research challenges include the appropriate representation of the learner/user in adaptive systems along with the other metadata models that impact on the adaptation process. With the potential for many distributed services gathering information about a user what appropriate mechanisms can be employed to ensure that the user is accurately represented and that as little duplication as possible occurs.

The relationship between expertise encapsulation and realisation of actual information requirements at runtime is also a valuable research direction. It would utilise any work done on vocabulary/ontology, but also help differentiate the roles in content management (content creation, knowledge sequencing, content/knowledge reconciliation, content delivery).

5. References

[Brusilovsky, 96] Brusilovsky, P.: Methods and techniques of adaptive hypermedia. In P. Brusilovsky and J. Vassileva (eds.), Spec. Iss. on Adaptive Hypertext and Hypermedia, User Modeling and User-Adapted Interaction 6 (2-3), 87-129.

[Brusilovsky, 02] Brusilovsky, P. and Nijhavan, H. (2002) A Framework for Adaptive E-Learning Based on Distributed Re-usable Learning Activities. In: M. Driscoll and T. C. Reeves (eds.) Proceedings of World Conference on E-Learning, E-Learn 2002, Montreal, Canada, October 15-19, 2002, AACE, pp. 154-161.

[Conlan et al, 01] Conlan, O., Hockemeyer, C., Lefrere, P., Wade, V., & Albert, D. (2001). Extending educational metadata schemas to describe adaptive learning resources. In Hugh Davies, Yellowlees Douglas, & David G. Durand (eds.), Hypertext 01: Proceedings of the twelfth ACM Conference on Hypertext and Hypermedia, pp. 161-162, New York: Association of Computing Machinery (ACM).

[Conlan et al, 02] Conlan, O., Wade, V., Bruen, C., and Gargan, M.: Multi-model, metadata-driven approach to adaptive hypermedia services for personalized eLearning. In: De Bra, P., Brusilovsky, P. and Conejo, R. (eds.) Proc. of Second International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems (AH'2002) Proceedings, Málaga, Spain (2002) 100-111.

[De Bra, Calvi 97] De Bra, P., Calvi, L. : Creating adaptive hyperdocuments for and on the web. - In: WebNet'97: proceedings of the WebNet'97 Conference, s.l., AACE Press, 1997, p. 149-155.

[De Bra, Calvi 98] De Bra P., Calvi L. : AHA: a generic adaptive hypermedia system. - In: Proceedings of the 2nd Workshop on Adaptive Hypertext and Hypermedia, Pittsburgh, Pa, 1998, s.l., 1998, p. 5-12.

[De La Passardiere, Dufresne 92] de La Passardiere, B., Dufresne, D.: Adaptive Navigational Tools for Educational Hypermedia. ICCAL 1992: 555-567

[Eklund et al 97] Eklund, J., Brusilovsky, P., Schwarz, E. : A Study of Adaptive Linik Annotation in Educational Hypermedia. http://wwwis.win.tue.nl/ah/ 1997.

[Eklund, Brusilovsky, 98] Eklund, J., Brusilovsky, P., “The Value of Adaptivity in Hypermedia Learning Environments: A Short Review of Empirical Evidence”,http://wwwis.win.tue.nl/ah/, 1998.

[Eklund, Sawers 98] Eklund, J., Sawers, J. : Customizing Web-Based Course Delivery in WEST with Adaptive Navigation Support. http://wwwis.win.tue.nl/ah/ 1998.

[Espinoza, Hook 95] Espinoza, F., Hook, K. : An Interactive WWW Interface to an Adaptive Information System. In proceedings of the User Modelling for Information Filtering on the World Wide Web, a mini-workshop at the Fifth International Conference on User Modelling. http://wwwis.win.tue.nl/ah/ 1995.

[Fink et al 96] Fink, J., Kobsa, A., Nill, A. : User-Oriented Adaptivity and Adaptability in the AVANTI project. http://wwwis.win.tue.nl/ah/ 1996.

[Kay, Kummerfeld 95] Kay, J., Kummerfeld, R. : User model based filtering and customisation of web pages. http://wwwis.win.tue.nl/ah/

[Laurillard, 93] Laurillard, D., "Rethinking University Teaching: A Framework for the Effective Use of Educational Technology", Routledge & Kegen, P., 1993.

[Murray, 99] Murray, T. Authoring Intelligent Tutoring Systems: An analysis of the state of the art. International Journal of Artificial Intelligence in Education, 10, 98-129.

[Major et al, 97] Major, N., Ainsworth, S. & Wood, D. (1997). REDEEM: Exploiting Symbiosis Between Psychology and Authoring Environments. International Journal of Artificial Intelligence in Education, 8, 317-340.

[Specht, 98] Specht, M., "Empirical Evaluation of Adaptive Annotation in Hypermedia" in Proceedings of EdMedia, 1998.